AMERICAN ASSOCIATION
OF PETROLEUM GEOLOGISTS

# BULLETIN

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OF

# PETROLEUM GEOLOGISTS

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RAYMOND C. MOORE, Editor

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## AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS

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# THE PUBLIC SERVICE OPPORTUNITY OF THE OIL GEOLOGIST

GEORGE OTIS SMITH

*Address to the Association, Dallas, March 18, 1920.*

It is a new profession that I address tonight. A decade or two ago the American Association of Petroleum Geologists would have been at best a small group without public recognition. Indeed, it was only in the early 80's that the president of this association made the start in placing geology at the service of the oil industry. With Dr. I. C. White, theory blossomed into practice and the science of petroleum geology began in method and application of principle to take on the form of engineering activity. Rarely is a national society like this able to honor itself by having at its head the one who was the pioneer in the field of its activity; too often the slow progress of both art and science defers our recognition of the founders beyond the period of their active participation.

As I face you I can appreciate as never before the geologist's part in the economic program of the world. By special training you are qualified to render special service and what that service should be may be well worth our discussing at this meeting. Your qualifications as scientists and engineers need only incidental mention as we may refer to this or that type of service. My topic—the public service opportunity of the oil geologist—might have been more bluntly expressed in the pointed question: As oil geologists, what are you trying to do?

Two tendencies in geologic work are noticeable today, and I believe that both are in the right direction—geology is becoming more exact in method and result and geology is becoming broader in outlook. Perhaps indeed I might shift these two statements on to a single track and say it all in a single phrase—our science is becoming more useful. We dignify not degrade science when we make it useful; we dignify it most when we realize its relation to human welfare. Geology is at its best when geologic facts are made

George Otis Smith, Director, U. S. Geological Survey, Washington, D. C.

to serve humanity, by solving the broad problems of the best use of national resources of men and material.

The oil geologist even now is pioneering in a new field, not simply as the agent of his employer, but as the citizen who keenly appreciates the world's need of petroleum in time of peace as well as in time of war. By his training, the geologist is fitted to think clearly; by his experience, he is fitted to act effectively. So you men must more and more learn to look upon your profession as having broader scope, as having a national and social side as well as the personal and individual side. I am glad that I have come to think of geology as a phase of citizenship rather than as merely a branch of science. A connection does exist between geology and public service and there should be nothing to interfere with that connection; no bulkheads should stand between our science and our citizenship—between our scientific standards and our civic duties. Clear thinking and direct action are needed in both; faith in the efficacy of truth should stand out as a personal characteristic of the citizen-scientist—the willingness to think a matter through and then to believe that way and act that way and even vote that way. This recital of the faith that is in me explains, I trust, why I regard the oil geologist as truly in the service of the country, whether or not he is on the Government payroll. Therefore, the question that should always be open for debate before the American Association of Petroleum Geologists is—How can we serve the Nation?

First of all, the oil geologist has a large share of responsibility for the future. In addressing the Engineers' Club of Philadelphia, I spoke of engineering as prosperity insurance and quoted Professor Ely's concise definition of civilization as regard for the future. The geologist is popularly considered a dweller in the dusty records of the past—one who is ever looking backward; but you oil geologists, on the contrary, deal largely in futures, and as you look forward you, like the engineer, will be remiss in your duty unless you keep the factor of safety ever in mind as you work; you must insure the future welfare of our country.

The first duty of the oil geologist is self-evident—to find the oil. To discover a resource that is so deeply hidden seems almost the trick of a magician and the unscrupulous expert is willing enough to enshroud his acts in mystery. Yet oil geology is not magic but simply common sense backed up with a large collection of carefully

observed facts; the plane-table has taken the poetry out of your profession, if indeed there ever was even blank verse in it. The stimulating and strengthening element in the growth of oil geology has been the promptness of the test to which your judgments are subjected. The drill shows up the value of your science before you can shift responsibility. That you have successfully met that severe test no one appreciates better than the Director of the United States Geological Survey, who for some years now has found himself at the head of a high-grade employment bureau. The hard-headed men of business, who formerly gave scant courtesy to science, now eagerly seek scientists. Yet even now, I doubt whether we estimate fairly the quality of our work. To convince a former chief of mine that the oil geologist is right more than half the time, I had a test made of the measure of agreement between the structure-mapping and the results of the drill. The study covered a number of townships of the Osage lands, a region which perhaps favors the geologist more than some others, but care was taken to include townships in which the geologic relations were not wholly plain as well as those where the structure had been worked out to the satisfaction of the geologist. A few productive wells were found near synclinal axes and some dry holes were found on anticlines, yet this impartial study showed that the geologist, when his work is tested by the drill, had been right 87 per cent. of the time. The public can ask of science no better percentage of successful achievement than that, and if the business of the country were conducted with the same degree of accuracy, the high cost of living would be a less troublesome economic issue.

Nor is it true that the Federal service, in its long-continued work in geologic investigation, has never been able to predict an oil or gas field before the drill discovered the oil or gas. This city of Dallas is a most appropriate place in which to mention the prophetic words of our chief geologist, David White, written in December, 1915, and printed the following month in the Geological Survey Bulletin 629, in answer to the inquiry of your own city officials: "Are new fields likely to be discovered; and, if so, where?" Mr. White expressed himself as convinced that detailed geologic work would indicate new fields to the west of this city, "for," as he said, "it is highly probable, if not certain, that within this zone, especially within its western half, there will eventually be found pools of both

gas and oil, some of which may possibly be as productive as the Petrolia and Corsicana fields." The later discovery of the Ranger and associated fields, comprising a great and still not fully defined district in Texas, shows that this statement was an underestimate of the future supply, but even with the increasing skill of the oil geologist, conservatism in statement is a becoming virtue, though we must not let that virtue become a fault. The well-trained geologist, with wide experience, must not be too timid, for the world looks to him for the additions to its present inadequate supply of oil.

An article in a current magazine describing the changed conditions in the commercial world bears the striking title, "Competition is the death of trade." Some of us may see elements of truth in even so complete a reversal of a well-accepted popular belief. However, I believe you will all stand with me on the economic platform that competition is the death of conservation. Lawmakers have wandered far astray in trying to secure to the people their share of the profits incident to the utilization of national resources, but you geologists who have been in touch with the industries founded upon our mineral wealth have observed too often that division into small fractions is not a good preliminary to economic use, and that haste makes waste. The stampede to a new mining camp and the boom in a new oil field belong to the pioneer days of individual grabbing rather than to the period of utilization for the benefit of the many. And no resource is more easily wasted than oil if individual desire for gain is given full sway and the larger rights of the people are lost sight of; nor on the other hand does any resource better lend itself to exploitation with a minimum of waste either of itself or of human effort. Petroleum stands out unique as the conserver of man power in its production, its transportation, and its consumption. Yet its fluidity which makes possible this saving in man power is a virtue that easily leads to loss; the program of waste begins in the oil sands and continues above ground with leakage and evaporation and the spectacular finale is often the tank fire. The oil geologists best understand conditions beneath the surface, and his peculiar responsibility therefore lies in protecting the oil sands from the effects of improper drilling and operation and in keeping the drilling program within economic limits. To secure the least expensive and most effective recovery of the oil in any pool, a forest of derricks is not necessary, however attractive it may appear

in the oil company literature. How many wells are needed is a geologic question, pure although not simple.

The geologic problem of spacing wells in the interest of true economy has been largely hidden from view by several layers of legal complications. The fugitive nature of water and oil and gas is expressed in the judicial opinions by likening them to wild animals and classifying them as minerals *ferae naturae*. On this theory, possession of the oil along with the land is at best only temporary, and to put aside the legal terms for a moment, the rule of action adopted is "get while the getting is good." Further incentive to overdevelopment is found in the legal doctrines that follow from the general practice of oil operations on leaseholds. In its efforts to protect the lessor of oil land the law has put so much emphasis upon drilling to prevent draining away from the leased land that it really somewhat obscures the rights of adjoining owners to their share of the oil. It seems to a layman that the law tries to construct a gate that swings only one way, and oil operators have been so human as to need little help from the law in this respect.

Leaving now the legal rights and coming down to what a geologist sees as the practical equities of the question, first of all we think of oil as not a wanderer or fugitive under the face of the earth, except when it is disturbed by the act of man. Of course, I speak in terms of time as measured by man in his business relations—say 999 years or so; I do not refer to the migration of oil in geologic time from some unknown source to its structural abiding place of today. The geologist's view is that before the first well taps the oil sand the oil is in a state of stable equilibrium, with an acre content practically as definite as that of a coal bed; that the recoverable oil content depends upon determinable geologic factors; the thickness and porosity of the sand and its continuity and saturation, the rock pressure and the gravity of the oil. The area of oil sands that can be made tributary to a single well is also dependent on these geologic facts; and the economic spacing of wells thus becomes an engineering question, like the determination of the number of shafts best adapted to mine a certain coal bed in a large block of land under one ownership. But just here appears an apparent difference between property rights in coal and oil; side lines do not extend beneath the surface for the owner of oil land, and trespass in the extraction of oil is not an actionable offense. However, just

among ourselves, as geologists, counsel not being present, a fair question is: Are we to be guided in our professional handling of this most valuable natural resource by the legal requirements alone, or, in the interest of the common welfare, are we to set up for our rule of action the equities founded upon the facts of geologic and economic science?

It is a nice problem to determine the golden mean between a large ultimate recovery per acre at a high cost and a large ultimate recovery per well at a lower cost—a balancing between more oil and less cost, between supply and price. Yet certain facts of experience stand out so clearly that little weighing of judgment is required. I wish more evidence were at hand concerning the acre content of oil and gas sands for all the productive fields. The work of Beal on oil and of Shaw on gas stimulates our desire for more of the quantitative facts, without which the planning of oil development is too empirical and the valuation of oil property too difficult. With cost of drilling increasing, the question is far from merely academic.

The country over, the drilling program generally adopted provides for one well to from five to ten acres. One extreme is given in the closely spaced wells of Spindletop, for which there was some warrant in the exceptional productivity of the oil-bearing formation. The other extreme can be found in the Cabin Creek field in West Virginia, where the area tributary to a well is about thirteen acres, an economical spacing of wells that is possible because the pool is monopolized by one corporation. At first glance the truth seems to be that facts of ownership have more to do with well spacing than facts of geology. If an oil company controls a large acreage in one block, fewer wells are necessary to mine the oil, and it is the owner of limited surface who seems to need to put down relatively more wells to extract the oil.

Now to the oil geologist the application of this phase of the subject appears plain enough. The planning of an economical drilling program is an engineering task to which the geologist can apply his best energies with credit to himself and profit to his employer, and the saving thus effected is conservation of the best type. Some years ago I set up as the ideal for an oil land law, "the highest percentage of extraction at the lowest cost to the consumer," and on private as well as public lands that is the practical end to be sought. But the oil geologist who sells his services to any operator whose

drilling program plainly has as its purpose the draining of land that the operator neither owns nor leases, is turning his back upon his opportunity for public service. Town-lot drilling is not only wasteful development, but it involves disregard of property rights. In short, the legality of the proceeding shuts our eyes to the fact that it is our neighbor's oil that we strive to get first. Defensive offset drilling is one thing, but offensive line drilling is quite another. The eastern speculator may not see beneath the surface to the extent of visualizing the source of the oil that comes to the surface on his company's lease, but the oil geologist knows that the acre tract thus exploited can not support an oil well in terms of the oil content of an acre of sand. So the duty of the oil geologist is plain, not only to set his face but to raise his voice against the unfair practice of mining oil with total disregard of underground property lines. Our friend, the eastern small-town banker, who lends his respected name to one of those widely advertised oil companies, with large capitalization but small acreage, can plead ignorance, but the geologist knows where the oil comes from. A gilt-lettered prospectus of an oil company came to my desk the other day and I was interested to see what productive property the assets included; one well on a 3½-acre tract, two wells on 1-acre lots and a half interest in another 1-acre well, and I was gratified to find that no geologist had lent the authority of his name to such a drilling program, which I regard both dishonest and unprofitable.

As the technical advisor of a great productive industry, no one should be more sympathetic than the oil geologist with the enactment and enforcement of "blue-sky" laws. You can conserve capital as well as oil. Not only do fraudulent promotions pilfer the savings of those who can not afford to lose, but such losses add materially to the hazard that is already of necessity large in the hunt for oil. The result is that the legitimate producer, whom you serve, finds it harder and more expensive to get the capital he needs. The good of the oil industry and the quality of its service to the country demand the elimination of the slick promoter, and the persuasive stock peddler who render no service nor have anything of value to sell; they are part of the parasitic growth that has sprung up between the operator, with his need for working capital, and the source of that capital. The large tribute thus extorted and wasted is too great a tax on the oil industry, and you men who know this fact must

take more than a passive part in the protection of investors. It is not enough for you to refrain from selling your own name to questionable projects, it is your bounden duty to set and demand the same high standard on the part of all your professional associates.

In advising its client, the public, as to the probable degree of truth in this or that prospectus, the United States Geological Survey perhaps errs on the side of weak optimism; the statement of opinion in the letter of advice that goes out may not be so outspoken or decisive as the opinion that some of us hold. We think too much in terms of the legality of the claims set forth, and when closely examined the wording of advertisements of oil prospects is found to be most cleverly chosen, so that we too are thrown off the path by the obstructions of legal technicalities, even if we can see over or through them. Too often we who aspire to be worthy of the public's confidence, hesitate to denounce publicly what we know to be a fraud, even though we could not make a legal case against it, and therefore we content ourselves by saying that the reputed expert on whose report so much is based is not a member of any of the national engineering or geological societies. In this practice I do not feel at all satisfied that we go far enough, but with the Government official relying in this way upon membership in the technical societies as an index of professional integrity, it at least follows that there is put upon you the obvious obligation to keep your standards high. Membership in this American Association of Petroleum Geologists should carry its guaranty of both professional ability and moral reliability.

The oil geologist's opportunity to serve the investing public thus becomes in part the opportunity of an educator. There is much misunderstanding about the oil industry wholly apart from that caused by misrepresentation, and you who best understand oil and its differences from more simple resources, such as cotton and corn and hogs and pine, are the ones to inform the public. There is too much glitter to the oil industry. "Great commercial romance" is the literary term applied to this every-day kind of business of taking a dirty fluid out of a hole in the ground, pumping it around, and then at a vile-smelling plant refining it into salable products. Yet when we try to strike a pessimistic note, and write a magazine article to prove the threatened scarcity of petroleum, we embellish it with pictures of gushers and of the biggest oil well in the world. Who ever saw a picture of a "duster" that had cost $25,000, or even

$100,000 or more, exhibited to the public view except as the deepest hole in the world, or whoever saw the statistics of dry holes spread upon the record except in an equally dry Government report?

The geologist's unique qualification for public service is his sense of time. With his eye trained to see far back into the earth's remote past, he is better fitted to put correct values upon the episodes of the brief present day in which we happen to live. Intellectually, this longer view back into the past gives him poise; practically this ability to see things in true perspective leads him to plan intelligently for the future. No one estimates the future value of this expendible resource, petroleum, with truer vision than the oil geologist, and therefore no one can better urge that its present use be guided by future needs. You men assembled in these meetings have a large responsibility in oil conservation, and when I say conservation I have in mind not a sentimental theory, but the practical policy of use with full regard for future as well as present welfare.

The chief geologist of the United States Geological Survey and I are glad to concede that the official estimate of our country's oil reserves—6,500,000,000 barrels—is conservative, but an understatement of 50 per cent. would represent less than eight years' supply at the present rate of consumption. And what may soon be the demands for oil is beyond the vision even of a geologist. The secret of the capacity of Nature's storehouse is easier to unlock than the mystery of the progress in man's needs and desires. I think the oil geologists can estimate within 50 per cent. of the ultimate yield of the oil fields of the United States, but who could have foretold within 100 per cent. of the truth the increase in the consumption of gasoline even within the present decade. The latest clue that I have to the present demand for oil is an increase in apparent consumption in January of nearly four and three-fourths million barrels, as compared with December, or of more than five million barrels, as compared with the average monthly consumption of last year. This statistical item is enough to make the oil geologist even more alive to his duty in uncovering new pools and in aiding in every way in saving oil, man power, capital and material, in the work of winning the oil for the use of man.

We need more interest in the science of geology itself—the interest not only of the public generally, but of those of us whose days are filled with effort to apply the science to immediate practical ends

to make geology useful. I have elsewhere quoted that remark of a chemist: "We have science enough now to provide a beautiful, happy and good world. What shall we do with it?" The oil geologist is answering this question by applying the known truths of our science to one useful purpose, and to my mind this use for large human benefit is the hallmark of true value. Yet the research scientist is the one who has blazed the way along which you travel in your everyday work, and none should be so ready to accord to the discoverer his due meed of honor as those who have followed him and occupied the land he explored.

In a way, I suppose we may regard science as an expendible resource; those who apply science to the needs of man seem to require fresh supplies from which to draw for their use. At least it is true that each new advance in the engineering arts calls for a corresponding reinforcement by scientific truth. You geological engineers can walk alone along the old beaten paths, but when you venture beyond those paths the light of the beacon of geological science is most welcome; the newly discovered truth opens for you new vistas. The paleontologist, the geophysicist, the stratigrapher, and the structural geologist may be expected to aid the oil geologist in the future as in the past. The obligation rests upon you to keep at heart the interests of your science. You who have given so much of practical value to the science of geology surely have a real interest in seeing geologic research reach out for "something hidden behind the ranges." That you have built cities should not deaden in you the spirit of the trail-finder.

Nor can the oil geologist afford to cut off his own connection with research. The geologist who is more than a "rock-hound" or "outcrop chaser" is the one who can render the largest service. The oil geologist who knows most about the geophysics of oil sands will make the largest contribution to his generation, by furnishing facts by which waste or loss of petroleum can be avoided far below ground, where neither the eye of man nor the imagination of most men can reach.

One obligation remains to be mentioned—the opportunity that the oil geologist has to serve his country and his fellowmen. America needs oil today and our fellowmen will need oil tomorrow. During the war science in general was mobilized to meet a peak-load demand. Pure and applied science vied in the effort to render the service that

was needed by our nation and its allies, and this service brought in its train due recognition. Yet the peak of the world's need has not yet passed, and science can not demobilize. The strain is just as heavy as ever upon the oil geologist, whether he is in Federal or in private employ, and he can not escape this responsibility.

There has been, however, one change since the war; then America bent every energy to supply the Allied forces on sea, on land and in the air with motive power, and our oil wells and especially our oil storage met the emergency. Today, our need is a domestic need—the arts of peace are requiring more oil than we have. We are forced to think of America first, and the oil geologist of all public servants owes his active allegiance to the American hunt for oil. The American geologist, who on the signing of the Armistice realized that the hour had struck for the severance of professional relations with an allied nation and returned home to add his efforts to the new endeavor under his country's flag, saw clearly his duty. Those of us who have always been in American employ can equally wisely and patriotically continue to serve American interests and none other. American engineering and American capital are together entering the field of world-wide exploration for oil, and no oil geologist can be spared from this national project. Pioneering must continue at home, but it must also be extended to other continents, all in the effort to meet present needs and to provide for future requirements. The America of tomorrow is the vision that best inspires the public service of the scientist.

The oil geologist has won his place in the world; he is typical of the geologist who, as Rickard has said, has become the "pioneer of commerce" and "a real partner to engineer and capitalist." He can face these other Americans who are making large contributions to the Nation's progress and demand comradeship on equal terms; and this independence that has come with usefulness is both his reward for service and his incentive to larger service. The oil geologist can truly be the architect of his own career, in that he can maintain the spirit of the scientist and select his opportunity for service, in full confidence that his opportunity to serve his fellowmen is large enough to develop the best that is in him.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS

# CONSERVATION OF OIL AND GAS RESOURCES IN CALIFORNIA

R. P. McLaughlin

## INTRODUCTION

Conservation of the oil and gas resources of California has, for over four years, been provided for by State supervision covering the drilling, maintenance and repair of wells. A description of the work may be of interest to geologists and engineers for the reason that the technical or scientific element is predominent.

Natural laws, such as those governing gravitation and hydrostatic pressure, are universal in their operation. They are not limited by boundary lines of property owners, States or nations. It is hoped that the investigations in the oil fields of California have been systematized and recorded in such a manner that the results will be found useful, to some extent, in other localities. It is, of course, recognized that physical conditions vary in different fields and that a fixed program is, therefore, not applicable to all. However, it can be definitely stated that no plan for dealing with the problem will ever be successful unless it involves the scientific study and application of natural laws.

## FAVORABLE CONDITIONS

Whatever success has been attained through state supervision in California has been due to several favorable circumstances, which deserve recognition. (1) Governmental affairs under the administrations of both Governor Hiram W. Johnson and Governor Wm. D. Stephens have been such that the department has been able at all times to adhere to a definite policy without political hindrance or interference. State funds are expended under a definite budget system of pre-audit and control such as is followed in any well-regulated business. Assistants are employed under Civil Service regulations, insuring equal opportunity to all qualified

R. P. McLaughlin, State Oil and Gas Supervisor of California, San Francisco, Cal.

applicants. (2) A firm foundation of scientific oil field development had been laid by the managers and engineers of several large oil-producing concerns before enactment of the present law. These concerns, anticipating the advantage that would come from uniform application of scientific principles, assisted in its enactment. (3) The oil operators of the State have, as a whole, been in a receptive mood to heed reasonable suggestions and submit to necessary regulations. (4) The various members of the departmental staff have, without exception, loyally devoted their entire attention and energy to the work of the department. They have been personally interested in arriving at correct solutions of the problems presented.

## PRINCIPAL CAUSE OF WASTE

The most obvious and serious cause of waste in California oil fields has been due to water, which floods productive formations and quickly lowers their productiveness. Consequently, legislation has been aimed directly at that feature. The chief problem is that of confining water to its original strata, or so governing its encroachment that the utmost amount of oil can be extracted.

## GEOLOGICAL CONDITIONS

The first and most obvious step towards remedy or control of water conditions was a thorough study of geological details. The strata are, generally speaking, composed of soft clay, shale and sand, and have no great lateral continuity. The strata are frequently lenticular and thin out and disappear within a distance of two or three miles, or even less. No general rule of sequence of oil-bearing and water-bearing strata can be applied through an entire field, much less from one field to another. Unconformities or overlaps, as well as sharp folding of beds, add to the difficulties of solving underground conditions, which are, furthermore, frequently not indicated by observable surface outcrops or dips. Solution of a problem, therefore, involves a careful piecing together of all information furnished by various well records.

When the investigation of an area begins, all possible items of information must be gathered and compared for the purpose of finding a clue to the stratigraphic correlation. The rock formation must be observed for the usual characteristics of color, texture and hardness. The water in a certain stratum is sometimes characterized by its

odor, taste, temperature or chemical content, or the level to which it rises. The oil contained in a certain stratum frequently has a different specific gravity and viscosity from that in other beds. Cross-sections, contour maps and peg models are used extensively in collecting and comparing facts.

### ARTIFICIAL OR MECHANICAL CONDITIONS

After the stratigraphic sequence and the structure in a locality are determined, it becomes necessary to study and compare the physical or mechanical methods of water shut-off which have been either used or neglected. This branch of the study covers all the methods and tools involved in well drilling and is subject to constant growth and improvement. A broad view and training in engineering principles and knowledge of actual drilling operations, in addition to a fundamental knowledge of geology, are necessary in order to carry on the work efficiently.

Having attacked the problem of legal administration from its basic or scientific side, and having assumed that all oil operators would desire to inform themselves on the pertinent facts, an educational campaign has been carried on. The details previously mentioned have been rather fully covered in the published annual reports[1] of the State Oil and Gas Supervisor and need not, therefore, be mentioned at this time. The Bureau has, since April, 1919, been publishing the reports in the form of monthly bulletins, which briefly describe each and every operation upon which the department has passed. Special articles and reports are also contained in the monthly publication, which is distributed without cost to all operators and others who are interested. Individual maps of all California fields are prepared by Bureau engineers and revised frequently. These maps are sold at the cost of blue-printing.

### STATUTORY FORM OF ORGANIZATION

The administration of the oil and gas conservation law is under the general jurisdiction of the State Mineralogist, whose position, as head of the State Mining Bureau, is somewhat similar to that of State Geologist in many States. A special oil department of the Bureau was formed and placed under the direction of the State Oil

[1]Bul. Nos. 73, 82 and 84, Cal. State Min. Bur.

and Gas Supervisor. The writer has occupied the position of State Supervisor since its creation, and no public statement of the work would be fair or complete without a special acknowledgment of the freedom of action granted by State Mineralogist Fletcher Hamilton.

### STAFF

The staff of the department is composed almost entirely of men technically trained either as mining engineers, civil engineers or geologists. The men occupying the more responsible positions have all had several years' experience in the employ of oil companies. The technical staff of the Supervisor includes six deputies, four engineers, twelve inspectors and four draftsmen. The clerical work engages about a dozen persons. The central office of the Supervisor is at San Francisco and there are six branch offices situated in the several oil fields or districts. The business of the department, concerning oil operators, is transacted in the branch offices between the field representatives of the companies and the Deputy Supervisor in charge of the district. At each field office there are models, maps, cross-sections and all the various data used in determining the specifications to be applied to any well. The head office of the department has a complete duplicate file of all field records. Each deputy supervisor has assistants numbering from one to seven, depending upon the amount of business in his district.

### FINANCIAL FEATURES

The Department of Petroleum and Gas is supported financially by assessment levied directly upon oil lands and oil and gas produced. During the first four years of its work, the department expended $288,493.76, which, in a general way, amounted to a tax of not quite .8 of a mill per barrel of oil produced, or about $85.00 per new well drilled. The work of the department not only includes general supervision over new wells, but over wells which are redrilled, deepened, partially plugged or abandoned, and the drilling expenditures prorated for each individual well which has come under our supervision amounts to about $40.00 per well.

### PROFIT

The cost of supervision has already been more than repaid by profits from increased production. The detailed study of under-

ground conditions has, besides its direct aim of controlling water, led to the discovery of productive formations which had previously been ignored. The natural gas reservoir in the Elk Hills field has furnished wells making over one hundred million cubic feet per day. This discovery was directly due to the work of the department[2]. In the Coyote Hills field a great number of wells were actually drilled through an upper oil zone without its productiveness being recognized. The department recommended that water be shut off above the zone and wells bailed dry to test it. The result has been several wells which flowed at rates of from 400 to 10,000 barrels of oil per day.

Shortly after the organization of the department, several detailed investigations were made of localities where water had seriously interfered with production. Repair work was recommended and supervised, with results profitable to the owners. In the Kern River field one well, in a group of eight, was plugged and increased the total daily oil production from 135 barrels to 207 barrels and reduced the water production from 1,750 barrels to 121 barrels[3]. At another group of eleven wells, repair work reduced the daily production of water from 15,927 barrels to 240 barrels, while the oil production was increased from 25 barrels to 59 barrels. Following these demonstrations, many similar repair jobs have been carried on by the property owners without an initial investigation by the department.

The profit accruing from supervision of new drilling can not be computed for the reason that there is no way of knowing how good or how bad the work might have been without supervision. It is, however, generally conceded that there is a great deal more care exercised in drilling wells now than prior to State supervision.

About 3,700 wells have been drilled since the department was organized. This is almost one-half of the total number of wells now producing. The amount of money involved in drilling a well varies from $15,000 to $100,000, with the average probably about $40,000.

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[2]"Summary of Operations—California Oil Fields," May, 1919, Cal. State Min. Bur., pp. 4-8.

[3]Second Annual Report—Bul. 82, Cal. State Min. Bur., pp. 254 and 259.

### DETAILED METHOD OF SUPERVISION

The law requires that every operation affecting the drilling, maintenance or abandonment of a well shall be passed upon by the department prior to execution of the work. The manner of submitting the pertinent facts is provided for by blank forms, which are reproduced in our First and Second Annual Reports and need not, therefore, be described in detail further than to state that the data include the exact location and elevation of the well and also the casing program.

The detaled procedure of the department in passing upon the various phases of the problems involved in drilling a well may be interesting. All the vital recommendations from the department to oil operators are made in writing to prevent misunderstandings, and for the further purpose of having a complete record upon which to base future investigations and recommendations. Over 12,000 such reports have been issued.

The first report on a well deals with the depths at which casing should be landed and the methods by which water shall be excluded. This report is issued to the operator upon receipt from him of a "Notice of Intention to Drill a New Well." A typical report follows:

CALIFORNIA STATE MINING BUREAU
DEPARTMENT OF PETROLEUM AND GAS
REPORT ON PROPOSED OPERATIONS

No. P-4-2537.

Mr. W. O. Todd, Taft, Cal., July 25, 1919.
Bakersfield, Cal.
Agent for Standard Oil Company.

Dear Sir:

Your proposal to drill Well No. 9 (Hay), Section 36, T. 30 S., R. 23 E., M. D., B. & M., Elk Hills Oil Field, Kern County, dated July 23, 1919, has been examined in conjunction with records filed in this office.

Present conditions as shown by the records and the proposal are as follows:

The Notice States—"The well is 330 feet W. of Center Line of Section and 2,310 feet S. of N. line of Section. The elevation of the derrick floor above sea level is 1,350 feet."

Proposal—"We propose to use the following strings of casing, either cementing or landing them as here indicated: Size of Casing, 12½ inches; weight, 50 pounds; new or second-hand, ———; depth, 1,800 feet; (landed or cemented), cemented. Will complete well at about 3,000 feet with 10-inch casing if test on No. 7 proves

absence of water between gas, expected at 1,850 feet, and productive oil, expected at 2,500 feet. In event of water occurring between gas expected at depth of 1,850 feet, and productive oil, expected at 2,500 feet, we will land 10-inch casing as second water string at 2,475 feet. We estimate that productive oil or gas sand should be encountered at a depth of about 2,500 feet, more or less."

Recommendation—The proposal is approved, with the recommendation that if tests on (Hay) No. 7 show that there is a water-bearing formation between the gas expected at 1,850 feet, and productive oil expected at 2,500 feet, the formations between about 2,475 feet and 1,800 feet should be thoroughly mudded under pressure, and sufficient cement should be used in cementing the 10-inch at 2,475 feet to extend up around the casing to the shoe of the 12½-inch at 1,800 feet, so as to protect, as far as possible, the gas-bearing formations from infiltration of water.

R. P. McLAUGHLIN,
*State Oil and Gas Supervisor.*
By (Signed) R. D. BUSH, Deputy.

It frequently happens that after drilling is started conditions, other than those anticipated by the operator, necessitate a change of program. In such a case the operator files a "Supplementary Notice," which is handled as follows.

CALIFORNIA STATE MINING BUREAU
DEPARTMENT OF PETROLEUM AND GAS
REPORT ON PROPOSED OPERATIONS

No. P-4-2620.

Mr. L. B. Little, Taft, Cal., August 25, 1919.
Bakersfield, Cal.
Agent for Standard Oil Company.

Dear Sir:

Your supplementary proposal to drill Well No. 9 (Hay), Section 36, T. 30 S., R. 23 E., M. D., B. & M., Elk Hills Oil Field, Kern County, dated August 19, 1919, has been examined in conjunction with records filed in this office.

Present conditions as shown by the records and the proposal are as follows:

The Notice States—"The well is 330 feet W. of Center Line of Section and 2,310 feet S. of N. Line of Section. The elevation of the derrick floor above sea level is 1,351.6 feet."

Proposal—"If test on Hay No. 8 proves the absence of water between 1,200 feet and 1,800 feet, will cement 12½-inch, 50-pound casing at 1,200 feet and cement 10-inch casing as a water string at about 2,475 feet. Well to be completed at about 3,000 feet. If water is encountered in test of formations between 1,200 feet and 1,800 feet in Hay No. 8, we will submit further proposals.

"Note: This notice supersedes and nullifies our Notice of Intention to Drill New Well, dated July 23, 1919."

Recommendation—The proposal is approved, with the recommendation that, just before cementing the 10-inch casing at about 2,475 feet, the hole should be

thoroughly mudded under pressure in accordance with the following specifications: (1) The mud should be entirely free from sand or grit and have a specific gravity of about 1.15. (2) Circulation of mud to the surface should be obtained, then the exit of mud from the well should be stopped and pumping continued at a pressure of about five hundred pounds per square inch until no more mud can be pumped into the well.

Notify this office to witness the following operations: (1) Test of effectiveness of 12½-inch shut-off. (2) Final mudding under pressure. (3) Test of effectiveness of 10-inch shut-off.

R. P. McLAUGHLIN,
*State Oil and Gas Supervisor.*
By (Signed) R. D. BUSH, Deputy

When operations prior to making a water shut-off have been concluded and casing is landed or cemented to shut off water, the operator submits a "Notice of Test of Water Shut-Off." A representative of the department appears at the well at the time designated to witness such a test.

The effectiveness with which water has been shut off is determined by bailing the fluid to a certain depth, allowing the well to stand undisturbed and again running the bailer to determine whether or not the fluid level has changed. A typical report of such an inspection follows:

CALIFORNIA STATE MINING BUREAU
DEPARTMENT OF PETROLEUM AND GAS
REPORT ON TEST OF WATER SHUT-OFF
(BAILING)

No. T-4-2585.

Mr. L. B. Little, Taft, Cal., December 5, 1919.
Bakersfield, Cal.
Agent for Standard Oil Company.
Dear Sir:

Your well No. 9 (Hay), Section 36, T. 30 S., R. 23 E., M. D., B. & M., Elk Hills Oil Field, in Kern County, was tested for shut-off of water on December 3, 1919. Mr. R. M. Barnes, designated by the Supervisor, was present as prescribed in Section 19, Chapter 718, Status 1915, as amended, and there were also present C. L. Roos, driller, and G. L. Bonner, driller. Location of water tested, upper. Depth and manner of water shut-off: 1,297 feet of 12½-inch, 40-pound casing was cemented in blue clay at 1,297 feet, with 120 sacks xx cement by Perkins method; rotary tools were used in landing water string. Casing record of well, 15¾ inches x 125 feet, 12½ inches—1,297 feet. Reported total depth of hole, 1,302 feet. Hole bridged from xx feet to xx feet. Hole cleaned out to 1,302 feet for this test. At time of test depth of hole measured 1,299 feet. At 6:00 A. M., December 2, 1919, oil bailed to

xx feet, water bailed to (dry) 1,302 feet. At 10:00 A. M., December 3, 1919, top of oil found at xx feet, top of water found at 1,291 feet.

Result of Bailing Test—Mr. Roos reported: On drilling ahead for the test hard cement was found at 1,270 feet inside of the 12½-inch casing. The Inspector witnessed the following: (1) A little gas was coming from the 12½-inch casing. (2) The bailer brought up blue mud from a depth of 1,299 feet. While standing for the test 8 feet of muddy water drained into the hole in twenty-eight hours, the equivalent of 1.0 barrel in twenty-four hours. The shut-off is approved.

R. P. McLAUGHLIN,
*State Gas and Oil Supervisor.*
By (Signed) R. D. BUSH, Deputy.

Important mechanical operations are frequently inspected while they are being carried out. A report of the inspection of mudding certain formations follows:

CALIFORNIA STATE MINING BUREAU
DEPARTMENT OF PETROLEUM AND GAS
SPECIAL REPORT ON OPERATIONS WITNESSED

No. T-4-2631.

Taft, Cal., December 24, 1919.

Mr. L. B. Little,
Bakersfield, Cal.
Agent for Standard Oil Company.

Dear Sir:

Operations at your well No. 9 (Hay), Section 36, T. 30 S., R. 23 E., M. D., Elk Hills Field, Kern County, B. & M., were witnessed by L. G. Graves and G. Michaelson, representative of the supervisor, on December 23, 1919. There were also present W. N. Thompson, foreman and N. M. O'Neil, driller.

The operations were performed for the purpose of mudding formations between 1,297 feet and 2,475 feet, as recommended in Report P-4-2620, and the data and conclusions are as follows:

Records: 15¼ inches—125 feet; 12½ inches—1,297 feet, cemented; shut-off approved.

Mr. Thompson reported: The hole was drilled with rotary; no extra pressure was applied. It was not observed that the formations absorbed any great amoung of mud while drilling.

The Inspector witnessed the following: 4:30 P. M., mud circulating freely between 12½-inch and 10-inch casings. 6:00 P. M., 10-inch, 45-pound casing hanging at 2,473 feet; heavy mud circulating freely. 6:05 to 10:00 P. M., packing head was placed on 12½-inch casing and the space between 12½-inch and 10 inch casings packed off. 10:00 P. M., heavy mud under pump pressure of 200 pounds to square inch circulated through 10-inch casing; returning between 10-inch and 12½-inch casings, through 2-inch line to trough. Closed gate on return line from well and applied pressure.

10:05 P. M., well took very little mud. 10:25 P. M., gauge showed pump pressure of from 375 pounds to 400 pounds per square inch. Pump stopped. Shut-off steam, holding pressure on well. 10:30 P. M., pressure remained constant at 350 pounds per square inch. The mudding of the formations between 1,297 feet and 2,475 feet is satisfactory.

R. P. McLAUGHLIN,
*State Oil and Gas Inspector.*
By R. D. BUSH, Deputy.

At the particular well mentioned, a second string of casing (10-inch) was cemented at a depth of 2,475 feet, with 160 sacks of cement. A test was made; no water entered the hole, which was open thirteen feet below the casing shoe, and the job was approved by a written report.

### PRODUCTION REPORTS

After completion of a well, regular monthly reports are filed by the owner, showing the amounts of water and oil produced. Ordinarily, completed wells receive no special attention from the department unless water trouble develops in the neighborhood. The complete file of production reports of all wells is then available for study in determining the time and place where water appeared.

### CONCLUSION

In conclusion, it may be stated that the general plan of supervision based upon scientific or technical methods has unquestionably demonstrated its usefulness, and will undoubtedly be retained in California, even though details of administration may change to fit future conditions.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS

# RECENT OIL AND GAS DEVELOPMENTS IN WEST VIRGINIA

DAVID B. REGER

The search for further supplies of oil and gas in West Virginia has reached the intensive stage. Regardless of the fact that the lure of quick and fabulous profits has turned the eyes of many to the North Texas and North Louisiana fields, there remains a large number of operators who realize that fair profits may still be made in regions where small initial production is the rule. Their reasoning is based on the grounds: (1) That West Virginia oil is of premier quality, commanding the highest market price; (2) That there is a ready market for all the natural gas than can be produced; (3) That the industry is stabilized, there being pipe-line, storage, and refinery facilities ample to absorb all probable production; (4) That a highly trained personnel of drillers and workers of all ranks is available at comparatively modest terms; (5) That the high bonus paid for new territory in more spectacular fields is not in vogue, leases being for the most part obtainable on a straight yearly basis, without paying the exorbitant first cost that often turns the scale from profit to loss.

Development within the past few years has embraced four distinct lines of effort, as follows: (1) Drilling additional wells in the old recognized pools where small wells may be profitably operated, due to the enhanced price of oil and gas; (2) Drilling deeper wells in the hope of finding productive sands in lower horizons; (3) Searching for pools in those portions of the Appalachian geosyncline where the structure is comparatively flat and where proper locations are more or less conjectural; (4) Exploration of new territory southeast of the main productive fields. These four lines will be taken up in regular sequence.

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David B. Reger, Morgantown, W. Va. This paper is published by permission of the West Virginia Geological Survey.

### DRILLING NEW WELLS IN OLD POOLS

Encouraging results are being obtained at scattered locations in Monongalia, Wetzel, Marshall, Harrison, Doddridge, Pleasants, Ritchie, Wirt, and other counties of the northwestern region, new production ranging from the Pennsylvanian down into the Upper Devonian measures. Important new developments are being made in Calhoun county, with drilling mainly centering around the "Boggard Hole" Pool on Little Kanawha river, above Grantsville, where the Big Injun sand of the Mississippian is the main producer, while many gas wells have been secured at other points. In Gilmer county a Maxton sand (Mississippian) pool of considerable size has been opened on Laurel Fork of Tanner creek, with wells ranging from 5 to 100 barrels' capacity. In the same county an extensive gas development has recently occurred along the Chestnut Ridge anticline, both to the northeast and southwest of Glenville. In Braxton county a large gas field has been opened in the vicinity of Burnsville, where deep sand (Upper Devonian) production is the rule. In Kanawha county active operation is in progress on the north side of Great Kanawha river, fifteen to twenty miles east of Charleston, where production is mainly from the Weir (Mississippian) sand, both oil and gas being found in considerable quantity. On the south side of the Great Kanawha, the Cabin Creek oil pool, with production in the Berea (Mississippian) sand, is gradually being extended southwestward. In Lincoln county numerous small wells have been completed in the old Griffithsville pool and surrounding territory, with production mainly in the Berea sand. In Roane and Clay counties many new oil wells of moderate size and numerous gas wells have been drilled recently, with production from the Big Injun and Berea sands.

### DEEP WELL DRILLING

For several years a determined campaign has been carried on by some of the large gas companies in the hope of piercing the "Clinton" (White Medina of the Devonian period) sand, which is largely productive in southeastern Ohio. The main net result of all these efforts has been failure, as the "Clinton" has not yet been reached, owing to regrettable accidents that have caused most of these tests to be abandoned. Drilling has, however, been carried to greater

depths than anywhere else on earth, the Lake well of Marion county having been drilled to 7,579 feet, according to White[1], and the Goff well of Harrison county having reached 7,386 feet before being abandoned, according to the same authority[2]. Both of these extremely deep holes failed to reach the "Clinton" by a few hundred feet, but their records have furnished many valuable scientific facts, including accurate intervals to the Devonian measures, and temperature determinations. Several deep wells in western Barbour county have revealed a gas horizon in the Benson (possibly the same as the Bradford or Kane of the Devonian) sand, with rock pressures of 2,275 pounds or more and with commercial volume. Another deep test on the Volcano Dome of Wood county made a small amount of oil and gas in the Corniferous limestone or possibly the Oriskany sand (Devonian) horizon, at a depth of 4,527 feet, but the production was eventually drowned out by salt water, and a second well in the same locality, but higher on the dome, made 20 barrels of oil daily in what is probably the Speechley sand at 2,285 feet, according to White. Several other extremely deep tests in various parts of the State failed to get through the great shale barrier, consisting of several thousand feet of unproductive strata lying between the Catskill series (Venango oil group) and the Corniferous limestone.

### THE SEARCH FOR POOLS IN FLAT STRUCTURE

Many attempts are now being made to find commercial pools of oil in that region of comparatively flat structure lying along the Appalachian geosyncline between Parkersburg and the Kentucky state line, embracing portions of Wood, Wirt, Jackson, Mason, Putnam and Cabell counties. Some scattered pools of shallow oil (Pennsylvanian or Upper Mississippian) have been found, and in certain localities encouraging gas or oil production has been found in the Berea sand, the latter horizon being often impregnated with salt water. Slightly to the east of this region a pool of some promise has recently been opened in the extreme northwestern corner of Roane county, the initial well being credited with 100 barrels of

[1]I. C. White, Ohio Gas and Oil Men's Journal, Vol. 1, No. 2, September, 1919, p. 17.

[2]I. C. White, Introduction to Barbour, Upshur and western portion of Randolph report, W. Va. Geological Survey, p. IV; 1918.

natural production daily from the Berea sand. Active drilling is now in progress in the neighborhood.

### NEW TERRITORY SOUTHEAST OF THE MAIN FIELDS

A very considerable amount of drilling is now in progress in several counties southeast of the main developed fields and closely bordering on the region of high carbon coals. Several wells of commercial size have been drilled in northern Nicholas county, with gas production from the Big lime (Mississippian) and other horizons. In northwestern Fayette, gas production in considerable quantity has been obtained in the Weir (Mississippian) sand and two wells have been lately completed in the extreme northwestern corner of Raleigh county, one of which is credited with 2,000,000 cubic feet of gas daily and 900 pounds rock pressure in the Weir sand and the other with 4,000,000 feet in the same horizon. These wells are situated southeast of the deep Handley syncline and reveal important new production, the extent and volume of which is still entirely conjectural. In Boone county the Berea sand development of the Cabin Creek pool has been extended several miles southwestward to the waters of Big Coal river, several comparatively large wells having been completed and drilling being in active progress. In the same county several wells have been drilled along or south of the Handley syncline, one of which is credited with 2,000,000 feet of gas daily in the Big lime. Much farther south, in the northern end of Wyoming county, a well is now drilling, which is reported to have showed 500,000 feet of gas in the Maxton (Mississippian) sand. Farther southwest, in northern and central Logan county, several wells have been completed near the Handley syncline, with no commercial production, drilling, however, being still in progress.

### FORECAST OF FUTURE DEVELOPMENT

Aside from the large number of new wells which still remain to be drilled to the known productive sands in the old fields, where the territory is largely proved, the regions that apparently offer most hope of future new production are the following: (1) Northern Nicholas county, where a considerable amount of gas may be expected from the Big lime and other horizons; (2) Northern Fayette, where Weir sand gas production and possibly some oil from the Weir or Berea sands will probably be obtained; (3) Northwestern Raleigh

county, where present indications point to a considerable gas field in the Weir sand; (4) Central Boone county, where large quantities of gas will most likely be found in the Big lime and Berea sand along the Warfield anticline, and where a further extension of the Cabin Creek (Berea sand) oil pool is confidently anticipated north of the Handley syncline; (5) Southern Boone county, where it seems probable that gas production in considerable quantity may be expected from the Big lime and possibly other horizons; (6) Northern Logan, where much more gas production is probable from the Big lime and Berea; (7) Southeastern Logan, where gas production from the Big lime, Weir, or Berea, would be expected on the rising structure south of the Handley syncline; (8) Southwestern Mingo, in the vicinity of Williamson, where recent completions in Pike county, Kentucky, indicate an oil pool of profitable size; (9) Northern Wyoming county, where gas production appears probable along the Pineville anticline; (10) The flat structure region along the Appalachian geosyncline in portions of Wood, western Wirt, Jackson, Mason, Putnam, and Cabell counties, where various shallow sands and probably the Berea sand may prove to contain commercial deposits of oil, but where there will undoubtedly be many failures, owing to the lack of definite surface indications; (11) An attempt will undoubtedly be made in the northeastern part of the State to secure gas production from the Speechley (Devonian) sand, lying several hundred feet below the Venango group, based on the large number of gas wells now being obtained in that horizon in the vicinity of McKeesport, Pennsylvania, one well having already been reported as a Speechley gasser in Tenmile District, Harrison county; (12) The attempt to reach the deep Clinton sand will likely be continued, probably along the Chestnut Ridge (Warfield) anticline, which passes entirely across the State, or on the Volcano dome of Wood county.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS

# THE CEMENTATION PROCESS IN SANDSTONE

ROSWELL H. JOHNSON

That the lateral limitation of many oil pools is the result of a more thorough cementation rather than the occurrence of water or a thinning of the bed or of an increased fineness of the grain is now well established. It becomes important therefore to know as much as we can of the progress of cementation and especially of its distribution.

The literature on the subject is not particularly helpful to the oil and gas geologist, as it has been written mainly from the standpoint of the metallic deposits. Thus in his classic treatise on metamorphism, Van Hise places the greatest stress upon the zone of weathering or solution, which is said to lie above the zone of cementation. It is evident that the cementation is considered as mainly the result of the deposition of material in solution in meteoric waters that have descended to lower levels.

As a matter of fact, in most oil and gas reservoirs the rock has never been in such a zone of exposure to meteoric water. The oil or gas sand when laid down was covered straightway by increasing depths of shales and other deposits so that the deposits in question were taken far below the reach of meteoric waters and the history of the cementation must be worked out from the connate water and other fossil water. These waters have produced far more cementation on the whole than Van Hise's zone of deposition from descending meteoric waters.

The history of cementation may be said to fall typically into five phases.

(1) The *connate water.* The water which is deposited with the sand may carry some material in solution which, under some conditions, may be deposited as cement. We know that coquina, of quite recent origin, will nevertheless be somewhat cemented and it is probable that the connate water enriched by solution was the active factor. However, on the whole, this phase can not be con-

Roswell H. Johnson, University of Pittsburgh, Pittsburgh, Pa.

sidered important for the reason that as the deposit in question becomes covered by a heavier and heavier overburden, the pressure on the water is therefore also increased, which increases the solvent action, so that far from deposition taking place it would seem that cement might be actually redissolved were we dealing with connate water alone.

(2) But there is a second phase, that of the *invasion of fossil water*. The compacting of the strata, especially the shale, is bound to extrude very great quantities of water. Such water in its migration will of course follow the lines of greater porosity, so that sandstone beds will receive water connate to the shale beds which would be richer in dissolved material, owing to the less silicious and more finely divided state of its particles. Cementation in this phase would therefore seem to be greater than in the first phase. However, since the depths from the surface is for the main part increasing throughout this phase, there is the same difficulty that we met before, that the waters are capable of holding in solution more and more material.

(3) As the heat and pressure become greater with increasing overburden and stresses make themselves felt, *hydrocarbons* are produced and enter the sandstone reservoirs in increasing amounts, to be held there by differential capillarity. Gas is more abundant at first because we find Quaternary deposits giving gas only thus far, where oil has not been contributed from below. But eventually oil, too, invades. But if the beds undergo such a history that the fixed carbon of their coal is higher than 65 per cent, then the end of the invasion is solely by gas. The earliest invasion, as the drift gas of Iowa shows, has relatively more nitrogen and carbon dioxide, thus approaching marsh gas, and is largely of bacterial origin. The gas which follows, which we may call second-stage gas, ordinarily has some higher hydrocarbons, and the gas entering last (third-stage gas), if the area enter this stage, is more purely methane, as at Poteau and Red Oak, Okla.

Now the importance of this invasion is that water is displaced from the reservoir and thereby cementation arrested. To study the distribution of closer cementation therefore, we must know the history of the hydrocarbon filled volume. This necessitates our adding to our knowledge of the paleogeographic history, the history of its folding and stresses.

The places of early lodgment of hydrocarbons in the reservoir is of especial importance as giving greater porosity. In homoclinal reservoirs these are at the original upper end and along the upper portion. It is also in the earliest anticlines. Conversely, ancient basins will be unduly cemented. Domes and anticlines formed only in the later history of a region will find the reservoirs already somewhat cemented as we shall see and hence have both the accumulation and the quantity of the hydrocarbon reduced.

It is to be observed that since the percentage of gas relative to oil increases with time, late folds will entrap an excessive proportion of gas relative to oil. Have we not here one of three explanations for "gas only pools," the others being individuality of the source bed and the fact that any small dome in a general homocline has its catchment so gas filled as to spill on up the dip much of its earlier trapped oil? The increasing proportion of gas in late invasions helps to explain some accumulations of gas on basinward sides in some pools where complete gravitional separation has not been effected. Mills has shown that the loss of water vapor to gas reservoirs concentrates fossil water density, but this factor is relatively slight in this connection.

(4) *Phase of increasing solution.* As the weight of overburden and other stresses increases the heat and pressure, the waters become increasingly enriched. This has been shown in the deep Geary well. Cementation therefore is not only not increased but actually decreased in this stage.

(5) Eventually, since our drilling is done on land areas, *elevation of the reservoir* begins. Now decreased heat and pressure reduce the solubility and cause deposition of the materials which are of very slight solubility and which require heat and pressure to hold them in solution. Where the heat and pressure have been great enough, even quartz being taken into solution in pure water to be later deposited in this stage.

The word phase has been used, but these items are not strictly successive phases as they overlap to some extent and also oscillate as elevation and stresses oscillate.

These oscillations are especially important, because the expansion of the gas leads to movement backward and forward, facilitating the segregation and the gravitational separation of the oil and gas.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS

# NOTES ON THE OIL FIELDS OF WYOMING

CARROLL H. WEGEMANN

A brief paper on the oil fields of Wyoming must necessarily be but a summary of present knowledge. Inasmuch as the summary has been prepared on very brief notice, it is feared that much has been left unsaid. It is the writer's hope that this paper may offer some suggestions which will open lines of profitable discussion.

To one coming from the Wyoming fields to those of the Mid-continent, differences and similarities naturally suggest themselves. The Mid-continent is an area of complicated structural problems—complicated because as a rule so few facts can be gathered from surface observation. Wyoming structural geology is much simpler in that the structures at the surface reflect closely those below. There is less left to the imagination and hence less chance of error. It is pre-eminently an area in which to study oil geology and to work out theories of oil accumulation.

The oil fields of Wyoming in the approximate order of their importance are Salt Creek, Big Muddy, Elk Basin, Grass Creek, Rock Creek, Lance Creek, Mule Creek, and probably worthy of mention, Hamilton Dome. Some Wyoming friends would doubtless suggest many others, but it must be remembered that this is merely a summary.

Salt Creek is pre-eminently the great field of the State, the area of the productive territory in the upper sand being about 5 square miles, and in the second sand approximately four times that area. The story of Salt Creek is not yet told, inasmuch as there are three oil-bearing sands which have not as yet been tested by deep drilling. Big Muddy is probably at its height of production, Elk Basin and Grass Creek are on the decline. Rock Creek is a new field of large area which gives promise of large production, though it can not be considered as comparable with Salt Creek. Lance Creek is a new field which already has a number of large wells. The sands, however, lie at great depth and the distribution of the oil appears to be erratic

Carroll H. Wegemann, Denver, Colo.

and does not closely follow structure. Mule Creek and Hamilton Dome are comparatively small new fields and they are mentioned principally because they show the possibilities of sands which have not been highly productive in other fields.

The fields which have been mentioned lie in widely separated localities: Elk Basin, Grass Creek and Hamilton Dome, in the Big Horn Basin, which lies west of the Big Horn Mountains; Salt Creek, Big Muddy, Lance Creek and Mule Creek, in that larger basin between the Black Hills on the east, and the Big Horn Mountains on the west, and Rock Creek in a third great basin which is called the Laramie Plains. All the fields lie on the borders of the basins mentioned, and may be considered as anticlinal waves adjacent to the mountain uplifts. There are innumerable folds of which no mention is here made, some of which have yielded large gas production or small quantities of oil. A few folds are as yet untested.

The oil sands, which yield commercial production or shows of oil, are almost as numerous as are the fields, and occur at many horizons in the stratigraphic column. There are oil impregnations in the Madison limestone, which is Mississippian; production in the Amsden and Embar formations, which are Pennsylvanian; in the Chugwater Red Beds, which are Jura-Trias; in the Sundance formation, which is Jurassic; in the Morrison, which is probably also Jurassic; in the Lakota of the Lower Cretaceous and in numerous beds of the Upper Cretaceous, the Dakota, Muddy, Mowry, Wall Creek or Frontier and, lastly, the Shannon. The greatest production comes from the Frontier or Wall Creek sands, which are the productive sands in Salt Creek, Elk Basin, Grass Creek and Big Muddy. In the Rock Creek field, production probably comes from the Muddy sand at the base of the Mowry shale; in the Lance Creek field, from the Dakota sand; in the Mule Creek field, from the Lakota, and in Hamilton Dome, from the Embar. There are several other small fields which obtain heavy oil from the Embar and mention of Hamilton Dome may be made merely because the oil from this field differs from other Embar oil in that it contains more than 25 per cent gasoline.

As noted above, all the really commercial fields are found on closed anticlines. These folds are much more pronounced than are the folds of the Midcontinent field. Dips on the flanks of the folds are seldom below five degrees, and more frequently range from 10 to

30, and even higher. Small production has been obtained from terraces, but so far as the writer is aware, only from formations in which the sands are fine-grained, so that the oil passes through them with difficulty and is therefore trapped on the terraces by friction which is sufficient to counteract the impelling upward force or combination of forces, whatever these may be.

The size of an oil pool in Wyoming appears to bear a direct ratio to the area of the sides of the anticline on which it is found; in other words, to the gathering ground from which the oil has accumulated toward the crest of the fold. At this point reference is perhaps made to theories as if they were facts, but this particular theory in the Wyoming fields appears to be substantiated. The east limb of the Salt Creek fold, for example, which fold bears the largest oil pool yet discovered between the Mid-continent field and California, is twenty-five miles in length from the crest of the fold to the axis of the syncline on the east—in fact, the rise of the beds is uninterrupted from the axis of the Great Basin lying between the Black Hills and the Big Horn Mountains—to the crest of the Salt Creek fold, which is situated on the southwest side of this basin. All the other important fields which have been mentioned have gathering grounds of wide extent. Most of the folds which have been proved by drilling to be barren are cut off from drainage areas by adjoining folds, as pointed out in the report by Lupton and Hewett on the "Anticlines of the Big Horn Basin."[1]

As above suggested, oil accumulations occur on more pronounced folds than do those of the Mid-continent field. Structures with low dip or terraces which, in the Mid-continent would carry commercial pools, in Wyoming are barren. It would seem that in Wyoming there was not so much oil formed per unit of area as in the Mid-continent field and, therefore, it took a much larger area to form oil sufficient for a commercial pool. The writer is indebted to H. W. Lowrie for the suggestion that the great extent and uniform porosity of the sands may be accountable for the fact that oil has been replaced by water on most of the terrace structures.

The point to which the writer is leading in the above statements, and to which some of his friends may take exception, is that, in the

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[1]Hewett, D. F., and Lupton, C. T., Anticlines in the Southern part of the Big Horn Basin, Wyoming, U. S. Geol. Survey, Bul. 655, 1917.

Wyoming fields oil found its way from shale into sandstone in very minute quantities over broad areas involved in the folding and worked its way through the sands for great distances laterally to reach the crest of the folds. There does not seem to be any evidence that faulting or jointing is involved in the process. It may well be that the oil was produced at the time of the folding by the slow heat generated by the pressures which produced the fold, combined with the enormous weight of the rocks above. It may even be that these pressures had much to do with the forcing of the oil from the shale into the sandstone, inasmuch as the pores of the shale could be reduced by pressure more effectively than could the pores of the adjacent resistant sands and hence any fluid which the shale pores contained would be forced out into the sandstone.

That the accumulation of the oil has been a slow process, continuing long after the folds were made, appears to be shown by conditions in the Shannon pool, which lies about three miles north of Salt Creek. The oil is found in the Shannon sand, which forms the escarpment around the Salt Creek field proper, and accumulation has taken place against a fault with downthrow to the north, which throws the edge of the Shannon sand against shale and effectually seals it. This fault is one of a system of faults which cut the Salt Creek dome, trending in direction north 65 degrees east. This direction is fairly constant over the entire area of the field. The trend of the faults appears to be independent of the shape of the fold and suggests that the faults were not formed at the time the fold was made. They appear to be related to other faults, which are found over a broad area in Wyoming, and were probably produced by regional stresses. In the Salt Creek field they appear to be most pronounced near the crest of the fold and to die out on the flanks, which would be the condition were they produced by a slight warping of the whole area after the major folds were formed. The faults were, therefore, in the writer's opinion, formed subsequent to the time of folding. This point can not as yet be proved, but it is believed that all the facts point to its correctness. The natural conclusion is that if the faults were formed after the folding and the oil in the Shannon was accumulated against one of these faults, the time of the accumulation of the oil in the Shannon is much more recent than the time of the formation of the Salt Creek fold. If the oil was formed at the time of the folding, the accumulation has been going on through

a long period of time and may possibly even now be taking place.

A most interesting fact which has been demonstrated by the development of Salt Creek is that the pool in the second Wall Creek sand which lies about 260 feet below the base of the first sand, occupies a much greater area than does the pool in the first sand, in fact an area four times as great. The first sand is 150 feet in thickness, the second sand is only 40 feet in thickness. It is significant to note that the thicknesses of the sands have the same relation to each other as do their productive areas, but in inverse ratio. The difference in the size of the pools in the two sands suggests that approximately the same amount of oil has found its way into each sand and that the pool occupies a greater area in the second sand than in the first, largely because the second sand is much thinner. Had there been vertical migration between the two sands it would seem that the greater part of the oil would already have forced its way into the upper and thicker sand. The writer is becoming more and more of the opinion that the oil which is found in a sandstone has been derived only from a few feet or possibly a few inches of the shale adjacent to the sandstone. The first and second Wall Creek sands in Salt Creek are both Frontier in age. The shales adjacent to them are similar and probably carry similar carbonaceous material. The amount of oil which has entered the two sands under the same conditions of folding is therefore largely a function of the area of the shales in contact with the sands. It may be suggested that the oil is derived from shale lenses included in the sands. With this the writer should agree, but he would not limit the shales in which the oil has originated to those included in the sands.

A great question in which petroleum geologists are always interested is the origin of gas. If it were known why gas is formed in one place and oil in another, we should hold the key to many things. This subject has been discussed in several papers by David White of the U. S. Geological Survey, and it may be mentioned here merely to suggest one or two lines of thought. If it be true that gas is produced under conditions of greater pressure and metamorphism than those which produce oil, may it not also be true that the character of the sediments may be largely responsible for these differences? The pressures exerted on shale particles which lie between sand grains will certainly differ from those exerted on shale particles included in homogeneous shale under the same stresses, inasmuch

as the coarse sand grains necessarily protect to a certain extent the minute particles which lie between them. It may therefore happen that in adjacent fields in which the rocks have undergone practically the same pressures, the degree of metamorphism of the sediments may differ greatly, due to the original character of the sediments. In certain regions in the Mid-continent field there is evidence that the oil pools lie in belts at certain distances from some ancient land masses. Nearer the old shore lines or farther from them no oil has been found. This may be due to the variation in the character of the sediments which have just been postulated and which influences metamorphism as much as do the presence or absence of ancient plant life, which existed only in water of certain depth and of certain temperature.

Why Montana has produced only gas or very light oil, although the same formations exist there as are present in Wyoming, is an open question. It has often occurred to the writer that the minute plants, from which oil has in all probability been formed, lived in the ancient ocean only at certain temperatures. Temperatures in Montana were doubtless different from those in Wyoming and plant forms of different species may have existed. These possible differences in the ancient plant life may have something to do with the resultant product, which is oil in Wyoming and gas in Montana. These are merely suggestions and are not put forward as theories. They are matters which are subject to determination and on which work should be done, but it requires a skilled botanist to undertake this work. It is deeply regretted that our good friend, Mr. Davis, who began the microscopic study of the oil shales of Colorado, is no longer with us to carry on his work. We can not lay too much stress on the necessity for careful microscopic study of the shales adjacent to oil sands. This study must be made before we will ever begin to know the story of the origin of oil.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS

# A NEW TRENTON FIELD IN ILLINOIS

F. W. DeWolf *and* L. A. Mylius

## LOCATION AND HISTORY

The location of Illinois oil fields is approximately shown by the solid color on the accompanying map of the State (Plate I), and the so-called "Trenton" area, in which leasing has been very active during the past three months, is indicated by shading for the area extending from Westfield in Clark county, northward to Champaign county. The area in which prospecting has been recommended by the State Geological Survey, and which has been largely leased up, covers about 150 square miles.

This area is believed to be crossed by the axis of the La Salle anticline, in continuation from the main oil field, but the location of the axis can not be accurately determined from outcrops or from present drilling. The location of the axis farther northwest, in the vicinity of Pesotum, was suggested in Bulletin 16, some years ago, and drilling to the Trenton was recommended; but the definite limitation on the north of the Westfield pool, the thinning of the Pottsville sands, and the absence of the underlying Chester beds to the north of the old Casey field, and the thinning of the Westfield lime checked development in that direction.

It is significant, however, that three wells had been drilled to the Trenton, south of Westfield, the first in 1910, which have had settled productions of from 2 to 5 barrels each per day, from a depth of about 2,400 feet. Under prices then prevailing, such wells were considered unprofitable Recent prices have altered the situation, especially in the light of continuous production, with only slight decline at the old Trenton wells. In the autumn of 1919, the Smith well was drilled into the Trenton to a total depth of 2,426 feet and settled to 20 barrels per day. The recently drilled offset well has apparently settled to a production of 30 barrels per day. The gravity of the shallow oils in this area varies from 29 degrees to 35

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MAP SHOWING THE ILLINOIS OIL FIELDS (SOLID) AND RECENTLY RECOMMENDED AREA (SHADED) FOR TESTS OF THE TRENTON

degrees Baume. These oils have a semi-asphaltic base. The Trenton oil has a gravity of 38 degrees Baume and has a paraffin base.

Immediately after the Smith well came in, the Geological Survey made an examination of outcrops along the Embarrass river and elsewhere, made a study of very shallow drilling which had been done near Warrington and Oakland in recent years, without attracting much attention, and re-studied old records for an area extending to Champaign county. As a result a leaflet was issued recommending the zone shaded on Plate I. Most of the area has now been leased, several locations for deep tests made, and a number of shallow wells are drilling. One company, at the suggestion of the Survey, is prospecting the structure with shallow diamond-drill holes along three cross-sections, about nine and twelve miles apart, and by intermediate drilling.

## THE ROCK COLUMN

Several unconformities exist in the formations underlying this area, and no single log is representative, but the following observations from the Smith well, based on study of samples of each screw, are worthy of record:

| FEET | |
|---|---|
| 290 | Surface and Pennsylvanian. |
| 790 | Mississippian limestone and shale. |
| 105 | Upper Devonian shale. |
| 890 | Devonian and Silurian limestone. |
| 260 | Richmond or Maquoketa lime and shale. |
| 142 + | Trenton (Kimmswick). |

The Pennsylvanian beds in part are tentatively regarded as of Pottsville age. The Mississippian "Westfield lime" is probably not the Ste. Genevieve and St. Louis, as in Lawrence county to the southeast, but probably belongs to the Osage group, including Warsaw, Keokuk, Burlington. The Upper Devonian shale carries Sporangites and is considered to be equivalent to the Sweetland Creek shale of Iowa and northwestern Illinois. The Devonian limestone probably is Hamilton, but may include Onondaga. It may not be separable from the Silurian Niagaran. A sand at least locally developed is by some thought to be equivalent to the Clinton sand of Ohio. The shale above the Trenton is Richmond or Maquoketa, which at outcrops in northwestern Illinois is an oil shale. The Trenton itself appears to be a crystalline limestone of

the Kimmswick phase, common in southwestern Illinois and Missouri.

The core drilling above referred to will probably be carried in most cases to the base of the Upper Devonian shale, but in one or two locations may be extended to the Trenton. If so, a good chance for finer correlation will be offered. A piece of Trenton as large as a brick was obtained from a recent shot and is now being split up for study and analysis. It does not appear to be much dolomitized, if at all.

### STRUCTURE

The structure of the field remains to be determined in detail, but westerly dips along the Embarrass in Coles county indicate that the crest of the fold probably lies some distance to the east. On the other hand, outcrops and shallow well records indicate flat or gently east-dipping strata in the eastern part of the zone recommended for drilling. The diamond drilling will reveal the conditions rather accurately, and the Survey will issue a limited number of progress blue-print maps from time to time to the active operators, practically all of whom are furnishing logs and samples of cuttings for this purpose.

A significant feature is the rise of the axis of the fold to the northwest. Thus, the Trenton will be reached in the vicinity of Oakland well within 2,000 feet, and at still shallower depth to the northwest and north, whereas it is almost too deep to be considered at this time in Lawrence county, being perhaps 4,000 feet deep on the highest structure.

### POSSIBLE OIL HORIZONS

A number of wells produce gas and oil from the Pennsylvanian at depths as shallow as 200 feet in this region and are decidedly profitable. Shows of oil have also been found in the Mississippian, in the so-called Hamilton and Onondaga, in the Niagaran, and in the possible Clinton. These are possible horizons above the Trenton itself. The so-called "Corniferous" has produced for perhaps forty years at Terre Haute, Indiana, a short distance eastward, but the writer is not sure where it fits into the Illinois section. A recent Indiana well reports a show in a sand below the Trenton, which has at least the lithologic characteristics of the St. Peter sandstone. On the whole, it would seem that the work of the next few months may develop a field of considerable importance.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS

# PENNSYLVANIAN SEDIMENTATION AROUND HEALDTON ISLAND

J. W. MERRITT

## INTRODUCTION

Many attempts have been made by geologists and others working in the Healdton field to explain the peculiar form of the Healdton production outline, with its nearly straight line of boundary on the southwest side and its three lobes on the northeast side. (Fig. 1.) Perhaps the most common explanation is that the southwest side is bounded by a fault, while the other side takes its form from the peculiar shape of the structure, or else that the lobes are not due to structure and that sooner or later the indentations will be filled out by producing wells. Sidney Powers, in two articles published in Economic Geology (1917) and in the Tr. Am. Inst. Min. Eng. (1918), explains the straight southwest line as being probably due to the influence of steeply dipping pre-Pennsylvanian rocks upon later structure. He does not attempt to explain the irregular northeast outline.

The idea of making a study of the conditions of sedimentation in this field came to the writer during his work on the pre-Pennsylvanian structure and the nature of the unconformity below the Pennsylvanian. In reconstructing this pre-Pennsylvanian erosion surface in sections 5 and 8 of T. 4 S., R. 3 W., a limestone cliff was found between well No. 9, Roxana-Wirt Franklin, and Sinclair-Million & Thomas No. 5. The "big limestone" was encountered in the latter well at 104 feet above present sea level, and in the former well at 125 feet below sea level. The wells are diagonal offsets. This shows a relief on the old limestone surface of 229 feet in but a few feet of horizontal distance. The possibility of this being a sea cliff along the ocean side of the island was at once impressed upon the writer, and with this in mind he began to reconstruct conditions one would expect to find when the island was being cut by the sea

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at this point, and to apply the result to the interpretation of the facts found in drilling in this field.

This work was begun in the spring of 1918 by the writer while he was in the employ of the Roxana Petroleum Company. The writer greatly regrets that he was unable to finish the problem begun at that time. He presents this paper, with its suggested theory of sedimentation conditions based upon his incomplete work, with the permission of the Geological Department of the Roxana Petroleum Company, with the hope that the suggestions therein contained will encourage better and more detailed work upon this problem in

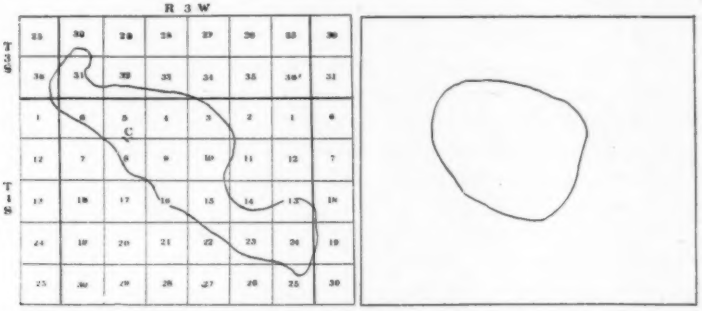



FIGURE 1. Production outline of the Healdton field. "C" shows where limestone cliffs were found.

FIGURE 2. Possible original outline of the "Healdton island." Scale same as Figure 1.

the Healdton region. The writer is greatly indebted for suggestions during his work to Dr. van der Gracht, Mr. R. A. Conkling, Mr. J. M. Herald, and others.

## THEORY OF SEDIMENTATION

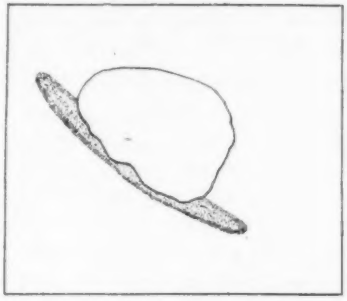
The structure of this theory is built upon the application of the facts of sedimentation now going on upon the borders of the continents to conditions as they must have been during the time of the submergence of the Healdton island.

Using well records of depths at which the "big limestone" (Viola) was encountered in various parts of the Healdton field for the determination of the pre-Pennsylvanian topography, we may reconstruct an island with a southwest slope of about 1,400 feet per mile (from

Million & Thomas, No. 5 to No. 1, Ardhoma-Walker, which lies about half a mile southwest) and a northward or northeastward slope of 1,000 feet per mile or a little less. This island or group of islands had a probable outline, as shown in Figure 2.

Applying the facts of present-day sedimentation to the conditions which probably obtained while this island was being submerged, the following effects of wave erosion and shore-line sedimentation may be expected:

(1) With an off-shore slope of 1,400 feet per mile in hard limestone, which is by no means a gentle slope, one would look for narrow



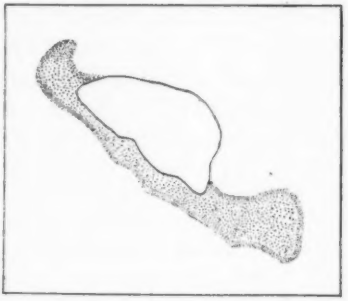


FIGURE 3. "Healdton island," showing shore line being cut back and sand spits in process of formation.

FIGURE 4. "Healdton island," with shore line cut back to present cliffs, beach and sand hooks completely formed. Compare with present production outline of the field.

beaches of lenticular bodies of sand scattered before wave-cut cliffs. The amount of back cutting and the height of the cliffs will depend upon the length of time given for this work by the pause in submergence. Seaward, these sands would change rapidly from coarser to finer, and would grade into shales, the sands becoming thinner and less frequent and the shales more frequent and thicker in the seaward direction. The initial slope of deposition of the sands on the beaches would be relatively steep.

(2) Since the island undoubtedly had valleys at the time that the sea was encroaching upon it, these valleys would cause small indentations in the shore line. The fact that such indentations occur in the production outline, instead of its being perfectly straight,

was noted by Mr. Herald and pointed out to the writer by him.

(3) As the shore is being cut by waves driven by landward winds, the debris would be carried more actively parallel with the shore by the consequent shore currents than seaward, where the water deepened so rapidly. With only slight variation in the direction of the on-shore winds, the currents would be now northwesterly and now southeasterly. As these currents passed the ends of the island the deeper water and the lack of shore line would slow them down and cause them to drop their burden. Sand bars would result. As the bars near the island reached low tide level, they would become a part of the shore, as far as currents are concerned, and the currents would move farther outward before depositing their burden. Figure 3 shows these bars being formed off the two ends of the island, at the same time that the shore line is being cut back.

(4) As these bars or spits extended seaward and were built more and more nearly to low tide elevation, they, too, would be affected by on-shore waves, and they would be turned at their ends into hooks. The extension of seaward spits, together with the continuous turning back of the ends into hooks, would cause to form in each case a wide-nosed hook or lobe at either end of the island (Figure 4). The sands of these bars or hooks, being worked over and over again, and especially affected by heavy storms, would be apt to be extremely lenticular and discontinuous—more so than those along the front of the old shore line. There would be strong dips seaward and also, due to piling up by heavy surf, steep dips toward the quiet waters behind the bars.

(5) In the quiet waters back of the sand hooks most of the sediments deposited would be the finer sands and clays carried around the hooks or washed off the north and east slopes of the island. Upon occasions of heavier storms or of heavier precipitation than normally, coarser sediments would be carried across the bars into these waters or would be washed from the island and deposited there.

(6) Since the island was finally depressed, relative to sea level, and covered by sediments of various sorts, valleys on top of the island would have to be filled also. These valleys have been found to lie between northwest-southeast ridges. After filling the valleys the sediments would settle or pack. The initial slope of deposition in the valleys would then be emphasized by this settling of the uncon-

solidated sediments. This settling would be greatest in the middle of the basins.

(7) It is not impossible that reef-building corals would be found in the more sheltered waters on the lee side of the island. Here, protected from the surf, but at the same time fed by gently moving waters, corals would naturally thrive. Some hints of limestones of this type have been found, but not enough work has been done to prove their presence. Coral-built limestones have been found by the writer, however, in Pennsylvanian rocks not far from Healdton, particularly at a point three or four miles west of Berwyn, and due north of Ardmore.

## EFFECT OF THIS TYPE OF SEDIMENTATION ON OIL ACCUMULATION

The natural slope of deposition, steepened by slump or packing of the unconsolidated sediments over and around the island, besides the lenticular form of the sands thus laid down, would be sufficient to cause accumulation of oil at this place, provided proper source of supply were near enough. The writer does not mean to imply, however, that there has been no folding here since the deposition of the Pennsylvanian sediments, for there is evidence of that, but he does mean to show that the conditions of sedimentation alone may have much to do with the location of production boundaries of this region. The presence of abundant salt water in streaks on top of the Healdton "structure," for instance, is probably due to the basin-like form of sedimentary deposition in the valleys during the submergence of the island.

Aside from the effect of subsequent folding upon the accumulation of oil in this field, production is apt largely to be limited by the type of sedimentation. Oil is found here in the sands. The distribution and arrangement of the sands is, therefore, an important factor. Oil will accumulate in discontinuous lenticular sands even though their attitude is monoclinal. The texture of the sand, also, has much to do with the limits of oil accumulation.

## SUMMARY AND CONCLUSIONS

Judging from the depth at which limestones have been encountered and from the discontinuity and attitude of the sands, it seems probable that, during the submergence of the Healdton island and its subsequent burial beneath the later sediments, its southwestern

shore line was cut back some distance and the sediments were strewn upon a narrow, steeply sloping beach which spread out at the ends of the island into hooked bars. In these sands and in those overlying them oil accumulated and the accumulation seems greatly to be controlled in a real extent by the conditions of sedimentation. The result of this control is evidenced in the shape of the outline of the limits of production, with its relatively straight southwest line and its three lobes on the northwest side. The irregular local dips of the sands in various parts of the field (showing no relation to the "Healdton structure" as such) may also be explained by the application of this theory of sedimentation.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS

# STRUCTURES OF WESTERN CHAVES COUNTY, NEW MEXICO

J. W. MERRITT

## INTRODUCTION

Early in June, 1919, the writer was asked to make a study of the oil possibilities in eastern New Mexico. He placed a field party in Chaves county and spent much of his time with them.

The work was rapid reconnaissance. First, all the roads of the region were covered and all anticlines encountered located on them. Following this, these anticlines were traced out and the different road locations were tied together, by walking out the anticlines. Soon it was found that instead of several small, isolated and scattered anticlines there were a few very long folds strikingly different in character from those encountered in the adjacent States to the east.

The peculiar character of these structures, when compared with those of Kansas, Oklahoma and Texas, became the source of much study to determine their value for possible future oil production.

In this work in the field, and in gathering field data and taking the photographs which accompany this paper, the writer is much

FIGURE 1. Northwest dip in Guadalupe limestone, showing steep dip suddenly flattening out. Note thin bedding in the limestone. Section 7-15-20. Facing S. 20 degrees W.

FIGURE 2. Cross-section of anticline at Tinnie, N. M., west of Chaves county. In this case the anticline coincides with a valley. Town of Tinnie in middle background. Facing N. 20 degrees E.

indebted to Mr. J. H. Williamson and Mr. W. W. Newby, members of his field party. He is also greatly indebted for valuable suggestions to many of the other geologists who were doing field work in that part of New Mexico.

## LOCATION AND AREA

The district with which this paper is concerned comprises the western half of Chaves county, New Mexico. It includes an area from twenty-five to fifty-five miles wide east and west and from seventy-five to eighty-five miles long north and south, and lies west of Pecos river. Chaves county is the second county from the Texas boundary and lies near the center of the southeast quarter of New Mexico.

## GENERAL GEOLOGY

The surface rocks of this portion of Chaves county are mostly Guadalupe limestones, covered in places by sandstones and gypsum of the "Red Beds." The Guadalupe limestones here dip southeastward at 50 to 100 feet per mile and strike, normally, from north 25 degrees east to north 35 degrees east. This monoclinal dip extends from the west crest of the Sacramento and White mountains, seventy-five miles eastward, broken here and there by anticlinal folding. In western Chaves county little faulting was found of sufficient magnitude to be worthy of note. The normal dip of the limestones

increases at the west side of the Pecos valley, where it disappears beneath the sands and clays of the valley and the artesian sand beds, where it reaches 200 feet or more per mile. In the artesian belt, south of Roswell, it is found 1,000 feet or more beneath the surface.

The Guadalupe formation is 500 to 600 feet thick here and is composed of thin-bedded light to dark gray, bituminous limestones, with scarcely a bed of sandstone or shale. The limestones vary in thickness of bedding from an inch or two up to three or four feet, and rarely exceed that thickness. Markers of color or texture of sufficient prominence to enable contour mapping are rarely present.

## STRUCTURE

Parallel with the normal strike of the limestones in western Chaves county three major folds were found. These anticlines follow remarkably straight courses across the country and are strikingly parallel with each other and evenly spaced from each other. The longest of these anticlines was traced in the limestone area from a point below Elk, in T. 16 S., R. 16 E. to T. 9 S., R. 21 E., and traces of the same fold were seen in the "Red Beds" as far northeast as T. 7 S., R. 23 E., a total distance of more than sixty-five miles. The fold was not followed to its southwestern limit. This anticline is called the Border Hills anticline because in a part of its course it forms the Border Hills at the west border of the county, about twenty-five miles west of Roswell.

FIGURE 3. Border Hills, looking S. 37 degrees W., from a point 200 yards south of the Roswell-Carrizozo road, in Section 9-11-20. These are anticlinal hills, and extend for several miles in a straight line.

FIGURE 4. East side of Border Hills, looking N. 10 degrees E., from the same point as Figure 3, showing strata dipping steeply to the east.

A second fold, parallel with the Border Hills anticline, and about ten miles southeast of it, has been found. This was traced more or less continuously from below Felix river in T. 15 S., R. 19 E., to the Six-Mile Hills, six miles west of Roswell, in T. 10 S., R. 23 E., a distance of nearly forty miles, and signs of its continuation out into the "Red Beds" northeastward have been noted.

A third parallel anticline was traced from southwest of Y-O Crossing on Penasco river in T. 17 S., R. 19 E., for more than twenty-five miles northeastward to T. 14 S., R. 22 E. This anticline lies about nine miles southeast of the second one just described.

Besides these major folds there are some smaller anticlines parallel to the strike which are traceable for short distances. Very few cross folds were seen, though one or two were found and mapped. One small dome, with forty or fifty feet of closure, covering less than a quarter section, was also mapped.

The larger anticlines are strikingly narrow. In few cases were they found with greater width than a mile from normal dip on one side to normal dip on the other side. Sometimes the folds pinch and swell from less than a half mile to over a mile in width. In almost every case the change from normal dip to structure dips is very sudden—often taking place in a very few hundred feet. The anticlines are usually symmetrical and the dips vary from a few degrees to 90 degrees. In the Border Hills anticline dips of 25 to 40 degrees are common. The other anticlines are flatter on an average, though some very steep dips occur locally. The apices of the

anticlines were found from a few feet to 500 or more feet above their bases. In Chaves county more frequently than not, the anticlines coincided with long ridges or ranges of hills. In Lincoln county, just west of Chaves county, however, a number of anticlinal valleys were seen.

The accompanying photographs show the character of some of these anticlines in cross-section and, also, in the case of the Border Hills, the relation of topography to structure.

## OIL DEVELOPMENTS AND POSSIBILITIES

Several years ago oil and gas were found in the top of the limestone at a depth of about 1,000 feet in wells drilled for artesian water in the valley south of Roswell. This oil has an asphaltic base, is very heavy, and contains a high per cent of sulphur. It was encountered in sands just above the limestone and in porous places in the top of the limestone. Since this bituminous limestone lies at the surface in the western part of Chaves county, its oil is not available. The Pennsylvanian limestones several hundred feet lower, however, are as bituminous or more, and may prove a source of oil in paying quantities, provided suitable conditions for oil accumulation can be found. A test was begun in Lincoln county, west of Roswell, on a large anticline, several months ago, but the writer is not informed whether this test has been completed, or what has been found up to the date of this writing.

FIGURE 5. Border Hills, looking N. 32 degrees E., from a point six miles northeast of Roswell-Carrizozo road, in Section 19-10-20, showing both dips of the anticline.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS

# A RESUME OF THE OIL SHALE INDUSTRY, WITH AN OUTLINE OF METHODS OF DISTILLATION

EARL A. TRAGER

## INTRODUCTION

Many articles have been written about the oil shales of the United States and many alluring figures have been published to show the enormous profits which are to be derived from relatively small deposits, but most of these statements have been made without careful investigation.

The purpose of this paper is to guide those investigators who are today making a scientific study of the future prospects of this industry.

The present status of the oil shale industry is most effectively expressed by Eglof and Morrell[1] as follows: "The increasing need of petroleum oil is steadily outdistancing the visible supply to such an extent that the oil shales of the west are already being considered, not only to make up this developing shortage, but as the future oil reserve."

In 1911, the total consumption of petroleum in the United States was only 217,000,000 barrels, while in 1918 the United States used 412,000,000 barrels of petroleum and during the same year it produced only 345,000,000 barrels. The deficit in production was made up by drawing on the reserves and by imports from Mexico. These figures will give some notion of the increased demand for petroleum in the United States alone.

The French petroleum commission states that, for the immediate future, France will need an enormous amount of gasoline per month to keep her industries going, and, since the production of petroleum in France is almost negligible, she looks to America for most of this supply.

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Earl A. Trager, Bartlesville, Okla., Geologist for the Empire Gas & Fuel Co., through whose courtesy this article is published.

[1]Eglof, Gustav and Morrell, Jas. C.: The supply of oils available from shales. Oil and Gas Journal, Vol. 17, No. 10, p. 46; No. 11, p. 42; No. 12, p. 44.

Another factor, which will tax the petroleum industry of this country very severely in the future, is the substitution of fuel oil for coal for use in the Navy and by most of the larger vessels of the merchant marine.

The General Motors Company estimates that in twenty years there will be fifteen million motors operating in the United States and that they will consume on the average two gallons of gasoline per day. Mr. Mark L. Requa states that, based on the present yearly increase in demand for petroleum products, the available supply of the United States will be exhausted in fifteen years.

These facts and statements certainly predict a great future for the shale oil industry of this country, inasmuch as the United States contains enormous reserves of valuable shale lands.

### A BRIEF REVIEW OF THE SHALE OIL INDUSTRY

The shale oil industry is not new either in this country or abroad. As early as 1694, Eele, Hancock and Portlock distilled "oyle from a kind of stone" from Shropshire, England.[2] In 1761, oils were distilled from bituminous shales for medicinal purposes, and it was found that they could be used as a substitute for turpentine and "oil of petre."

In 1815, a works near Sunderland, England, produced petroleum and ammonia from coal.

The shale oil industry made its appearance in France in 1830, when Laurent obtained paraffin by the distillation of bituminous shales. About three years later the Autun shales were exploited. From 1839 to 1864 the French industry flourished commercially, but about 1864 both the French and Scottish industries were paralyzed by the introduction of American and Russian refined petroleum. A second great blow was dealt the industry in 1893, when the French Government reduced the import duty on petroleum one-half.

Today there are five or six works in France producing petroleum from bituminous shales. Four of these plants are constructed on the Scottish system. In 1904, there were 184,000 tons of shale retorted in France and the average yield was 20.7 gallons of crude oil per ton of shale. Much toluol was produced from French shale oils during the war.

The Scottish industry owes its existence to James Young of Kelley, Scotland, who, in 1850, was influential in establishing, at Bathgate, a commercial plant for the extraction of oil from Boghead coal. This plant was in operation in 1851. The number of plants increased to nineteen in 1862. Then, in 1864, Young's patent expired and in this year there were thirty-eight new works erected. But it was at this time that the industry was checked in its progress by the importation of American kerosene, and a considerable reduction in the price of burning oil.

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[2]English patent 33, 1694, Eele, Phil. Trans., 19 (1697), No. 228, 544. Bacon & Hamor, Vol. II, p. 808.

Today there are four large companies operating in Scotland, and each handles about 2,000 tons of shale per day. There were three and one-half million tons of shale retorted in Scotland in 1916. The average production from the Scottish shales which are being used today is about 24.0 gallons of crude oil and about 50.0 pounds of ammonium sulphate per ton of shale retorted.

The operating expenses and cost of installation of the Scottish system, previous to the war, are worthy of consideration in this connection. The cost of installing a complete Henderson retorting plant was $350.00 per ton daily capacity. The cost of producing a barrel of crude oil, ready for the refinery was $1.86. This included mining, crushing, extraction of crude oil, and recovery of the ammonium sulphate.

In 1857, there were in the United States about fifty companies producing oil from bituminous shales and coals, but these rapidly disappeared after this date, because of the discovery of oil in Pennsylvania.

Now that the petroleum industry of this country can no longer supply the demand, and since the known reserve is rapidly being exhausted, the shale oil industry promises to appear on a much larger scale than was ever before attempted in this country.

## THE OCCURRENCE OF OIL SHALES IN THE UNITED STATES

Deposits of oil shale are known in the United States in Kentucky, Montana, Nevada, California, and the greatest and by far most important deposits are in the Uinta basin of Colorado, Utah and Wyoming. The shaded portion of the map shown below, Figure 1, represents the area where oil shales are known to occur in the Uinta basin and will give some notion of the magnitude of these deposits.

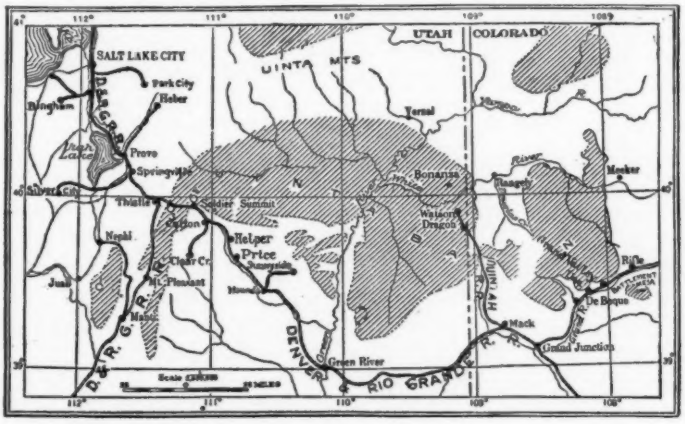


FIGURE 1. Oil shale areas in the Uinta basin.

The oil shale is found in the Green river formation which is Eocene in age. The rich ledges, alternating with beds which are very low in oil content, range from six inches to twenty-five feet in thickness. All the shale throughout the entire area lies practically horizontal. Figure 2 shows an oil shale mountain located near De Beque, Colorado. This photograph gives some idea of the enormous quantity of shale that is contained in a relatively small area.

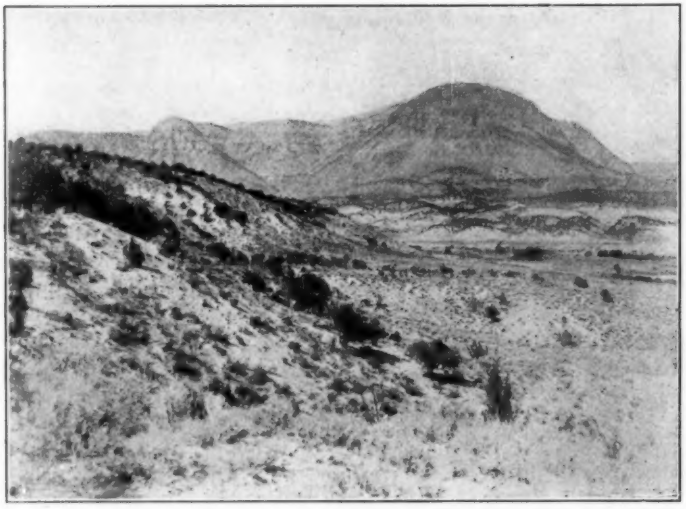

FIGURE 2. Oil shale near De Beque, Colorado. Mt. Blaine.

A more definite idea as to the amount of oil that may be derived from these shales may be had from the following statement: Throughout the greater part of the Colorado area there are three beds of shale, which total six feet in thickness, and which outcrop near the top of all the mountians. In many cases these three beds are under no great overburden and could be mined by stripping. These beds, which, taken together, are not over six feet in thickness, will yield more than 15,000 tons of oil shale per acre. This shale averages about 48.5 gallons of oil per ton, therefore, about 17,325 barrels of oil can be obtained from an acre of land which contains these

beds. Under these beds are about 500 feet of oil-bearing shale, containing a number of rich ledges up to fifteen feet in thickness.

There are about 4,000,000 acres of oil shale land along the south side of the Uinta Basin in Colorado and Utah that have been classified as valuable for its oil shales by the Government. Dean E. Winchester[3] has estimated that the Colorado portion will yield twenty billion barrels of crude oil, and the Utah area a like amount. The development of efficient distillation methods may increase this estimated recovery.

## INVESTIGATION OF OIL SHALES

Before the oil shales of this country are exploited on a commercial scale, it will be necessary to make a careful examination of the various deposits from many points of view: (1) accessibility, how favorably situated with reference to mining, retorting and marketing; (2) extent of any given deposit, to be determined by civil and geological surveys; (3) retorting the shales to determine the oil content, etc. There are numerous publications, or handbooks, that contain outlines for all of these studies, excepting the retorting of the samples. The purpose of this portion of the present paper is to suggest an accurate and scientific method of testing oil shales for their oil content. The work will be divided into three parts: (1) Description of apparatus suitable for field distillations or for preliminary laboratory tests; (2) description of apparatus adapted to more detailed analyses, or for research distillations, and serving as a guide for the use of advanced students or the commercial laboratory, and (3) outline of a method for the examination and distillation of the shale oil.

## OUTLINE OF METHOD FOR PRELIMINARY OR FIELD DISTILLATIONS

### APPARATUS AND METHOD OF TESTING

Before proceeding with the analysis, the student or operator should understand that oil shales do not contain oil as such. The oil is present in a substance known as "kerogen," and can be removed by heating, or destructive distillation, as the process is called. The method and rate of heating is very important, and upon this factor depends largely the type of oil that is produced from the shale.

To determine the oil content of a shale, first take a representative sample of the ledge and crush the shale so that it will pass through a ¼-inch mesh sieve. Thoroughly mix the crushed shale and weigh out exactly 8½ ounces (240.0 grams).

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[3]Winchester, Dean E.: U. S. G. S., Bul. 641, p. 141.

Place this unit of 8½ ounces in a 1-pint or a 1-quart (the latter is preferable) iron, mercury retort. Seal the cover with asbestos cement, or with an asbestos gasket.

If the distillation is to be conducted in the field, place the retort containing the charge of shale in a fire clay furnace body. Connect a 1½-inch iron condenser to the outlet from the retort, and have it slope about 40 degrees from the horizontal. A two to five-gallon water reservoir should be mounted at a somewhat higher level than the condenser. This may be connected to the condenser by means of rubber tubing and then, whenever the water in the condenser becomes warm, it can be replaced by cool water from the reservoir simply by opening a pinch cock. Place a 100 cc. graduated cylinder at the discharge end of the condenser, set the burner in place and the apparatus is ready to use. A field set up used by the writer is shown in Figure 3.

FIGURE 3. A field set-up for the preliminary distillation of oil shale, which was used by the writer.

The best source of heat for field or laboratory use where gas is not available is the 1½-inch D F C[4] hydrocarbon burner, using gasoline for fuel. After one is familiar with the use of the apparatus a distillation can be made with one to one and one-half pints of gasoline. Barthel blast lamps are the only other type of burner, known to the writer, which are satisfactory, but these are not on the market.

Be sure that all joints are tight, then begin the distillation by lighting the generator flame at the top of the burner. As soon as the generating chamber is hot, turn the burner on full force and close the generator valve. Leave the flame on full until the first drop of water or oil appears in the graduate, then turn the burner as low as it

[4]D F C, Denver fire clay.

will burn. The best results with this burner will be obtained if the pressure tank is kept within the range of 45 to 55 pounds.

Keep the oil dropping from the condenser at regular intervals, but do not run it out too fast or the oil will be "burned." As the flow becomes sluggish, slightly increase the fire under the retort. Be sure to watch the condenser at all times and not let it become too warm, or part of the oil will pass out as a gas and not condense. After the oil has stopped flowing and the bottom of the retort is a bright red hue, shut off the heat, for nothing is to be gained by heating beyond this point.

### CALCULATION OF RESULTS

The number of gallons of water and oil contained in a ton of the shale retorted can be read directly from the graduate, for, if 8½ ounces is taken for the charge, then each cubic centimeter of water or oil which collects in the graduate is equivalent to 1 gallon per ton; e. g., if the graduate reading is 10 cc. water and 50.0 cc. oil, then that shale contains 10 gallons of water and 50 gallons of oil per ton. The line of separation between the oil and water can usually be seen at once, if not, stir the contents and let the graduate stand for a short time and the division will become quite sharp.

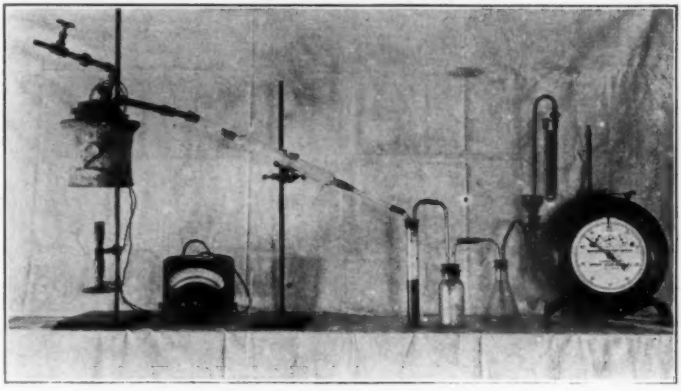

FIGURE 4. Apparatus for preliminary distillation.

The gravity of the oil may best be determined by pouring about 30 cc. of the oil into a glass cylinder, one about ¾ inch in diameter by 6 inches high, and then measuring the gravity directly by the use of a small hydrometer, one having 5 cc. displacement. Two hydrometers, one with a range of 20°–30° Bé, and the other 30°–40° Bé, will suffice for nearly all cases. It is most desirable to use hydrometers which contain a temperature correction scale, especially when working outside during the hot summer months. Figure 4 shows the arrangement of this

apparatus somewhat in detail. The water reservoir is omitted in this photograph.

## OUTLINE FOR LABORATORY STUDY OF OIL SHALES

The apparatus which is described in the following paragraphs is designed for complete analyses or for research distillations. By slight modifications to meet the requirements of individual workers, this apparatus can be adapted to perform any type of oil shale distillation.

The auxiliary parts of this apparatus may be selected with refinements adapted to the type of work for which the apparatus is to be used; e. g., the Wet Test Meter may be replaced by an inexpensive dry type gas meter. Figure 5 shows the general form of the laboratory set-up.

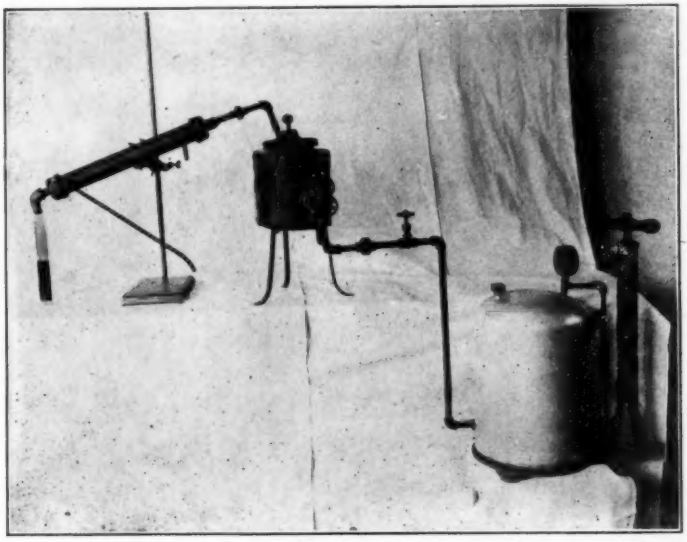

FIGURE 5. Apparatus for laboratory testing of oil shales.

In order to take temperature measurements and to use steam in these distillations, the cover of the retort used with this apparatus is fitted with a thermometer well, and a pipe for the introduction of steam. Figure 6 illustrates the method of tapping the cover to meet these requirements.

### DIRECTIONS FOR SETTING UP APPARATUS

Place 8½ ounces or 240.0 grams of pulverized shale in the retort and seal the cover in place. Set the retort in place in the furnace. Put a thermometer, or pre-

ferably, a thermo-couple in the thermometer well. Connect a glass or iron condenser sloping about 40 degrees from the horizontal, to the delivery tube from the retort and at the outlet of the condenser attach, by means of a two-hole rubber stopper, a 100 cc. graduated cylinder. Cylinders without lips should be used for this work to prevent leaks around the stoppers. Place a glass bend in the other hole of the rubber stopper. Connect a trap to the glass bend leading away from the graduate, an 8-ounce, wide mouth bottle is very desirable for this purpose. A gas wash bottle is connected to the

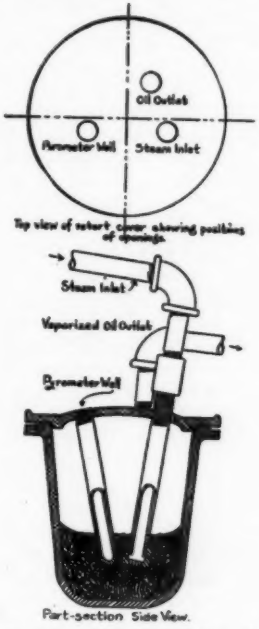


FIGURE 6. Diagram showing method of fitting thermometer well and steam connections to retort cover.

trap. Some standard form of wash bottle, or a 250 cc. erlenmeyer flask, may be used for this purpose. Into this bottle is placed a standard solution of sulphuric acid, which removes the ammonia from the gas. It is desirable to make up a standard solution of acid, such that each 5 or 10 cc. is equivalent to 1 pound of ammonium sulphate per unit per ton of shale. A drop or two of methyl orange may be added to the acid to serve as an indicator, to tell whether or not a sufficient quantity of acid has been used in the wash bottle to scrub out all of the ammonia contained in the shale gas.

The gas passes from the scrubber to a gas meter. A Wet Test meter is used for most accurate measurements, while for most purposes a diaphragm type meter, recording to 1–100 cubic foot will suffice.

If it is desired to know the amount of "fixed" gas which any given shale produces, pass the gas coming from the gas meter through a scrubber containing concentrated sulphuric acid, and from this scrubber to a second gas meter. The reading of this meter, when converted into terms of cubic feet per ton, represents the amount of fixed gas obtained from the shale.

To make distillations under pressure, or under vacuum, place a needle valve between the retort and the condenser.

### PROCEDURE FOR DISTILLATION

One or two large size Meeker burners, used with an asbestos chimney, similar to that shown in Figure 5, will give sufficient heat for laboratory distillations. Care must be taken to have all joints tight. When all is ready, place a small flame under the retort and start the water circulating in the condenser. Break the connection between the gas scrubber and the meter, and leave this open until the gas becomes inflammable, for the reading of this meter should represent the amount of combustible gas obtainable from the shale under examination.

It is advisable to record the time and temperature at which the first drop of water, the first drop of oil, and the first combustible gas is obtained. After these readings have been obtained, systematic readings should be taken at regular intervals. The flame under the retort should be increased as necessary to keep up a steady flow of oil from the condenser.

After the flow of oil has become very sluggish and the temperature inside the retort is in the neighborhood of 1000 degrees Fahrenheit, record the various readings and introduce a small flow of steam into the retort by opening the valve leading to the steam line. (See Figure 6.) The steam may be generated in any type of laboratory boiler. The best results are obtained if the pressure in the line is maintained at about 25 pounds. Allow the steam to flow through the retort until all the oil and combustible gas has been driven from the shale. The introduction of steam into the retort will greatly increase the amount of ammonium sulphate obtained from any shale. When the distillation is completed, a convenient way to clean the apparatus is to disconnect the graduate and pass a strong flow of steam through the retort and condenser.

### CALCULATION OF RESULTS

*Water.* The number of gallons of water per ton contained in the shale is equivalent to the number of cubic centimeters of water contained in the graduate, before the introduction of steam.

*Oil.* The number of cubic centimeters of oil contained in the graduate is equivalent to the number of gallons of oil per ton that may be derived from the shale.

*Gravity of the Oil.* Small hydrometers having a range of 10 degrees Bé and equipped with temperature correction scales, are most convenient for measuring the gravity of the oil. If, however, the quantity of oil obtained is too small for direct measurement by the use of a hydrometer, a pyknometer may be employed.

*Cubic Feet of Gas.* The number of cubic feet of gas obtained from the distillation times 3,765.4 is the number of cubic feet of gas obtainable from a ton of shale.

*Ammonium Sulphate.* Add the water which collected in the graduate below the oil to the standard acid in the gas scrubber. Titrate the excess acid with a standard solution of sodium carbonate, using methyl orange as an indicator. The number of pounds of ammonium sulphate obtainable from a ton of shale may be calculated from the amount of acid neutralized by the ammonia obtained from the distillation.

This method for the determination of the ammonia or nitrogen, which was first suggested by Dean E. Winchester, is the simplest and most convenient method for obtaining approximate results, but it is not an accurate method, because any relatively slight change in the method of distillation will affect the ammonia determination. The amount of heating, the temperature used, the introduction or absence of steam, and the presence of pyrite will all have an influence upon the amount of ammonia calculated, if the above method is used. A method which is much more accurate, one which will give uniform results, and one which is not subject to the variations encountered in the above method is outlined below.

### A MODIFICATION OF THE KJELDAHL METHOD FOR THE DETERMINATION OF NITROGEN IN OIL SHALE

This method is similar to that outlined in Technical Paper No. 64, United States Bureau of Mines, for the determination of nitrogen in coal, and is recommended by Martin J. Gavin, oil shale technologist for the Bureau of Mines.

The procedure is as follows: Pulverize a representative sample of shale to pass a 60-mesh sieve. Place 1 gram of this pulverized shale in a 500 cc. Pyrex Kjeldahl distillation flask with 30 cc. conc. sulphuric acid, 5 grams potassium sulphate, and .2 grams mercury.

It is advisable to fit a small funnel into the neck of the flask to prevent any loss by spattering during digestion.

Digest for 5 to 6 hours on a digestion shelf, using a small flame to begin with and gradually increasing it until a full flame is employed. Spent shale requires about two hours longer digestion than fresh shale. Fifteen minutes before digestion is completed, add a few crystals of potassium permanganate to the flask.

Upon completion, remove the flask from the digestion shelf and dilute the acid with water. Add some potassium sulphite (to ppt. the mercury), about 1 gram of zinc dust, an excess of concentrated sodium hydroxide, and a small piece of paraffin.

Connect the flask, by means of heavy-walled rubber tubing, to a Kjeldahl condenser, the inner coils of which must be made of pure block tin. It is advisable to use a connecting bulb tube between the flask and the condenser to prevent the alkali from boiling over.

Distill over into an erlenmeyer flask containing a known volume of N/10 sulphuric acid, using methyl orange as an indicator to prevent going past the neutral point in the case of a shale containing an unusually large amount of ammonia.

The distillation is usually complete when 100 cc. have passed over into the flask.

Titrate the remaining acid in the flask with N/10 sodium hydroxide and calculate the amount of ammonium sulphate in the shale from the amount of standard acid neutralized by the distillate.

## FRACTATION OF SHALE OIL

Inasmuch as there are no shale oil plants operating on a commercial scale in this country, very little is known about the quality of shale oil as compared with crude oil, and no standard method of distillation has been established.

The method of analysis which has been most commonly employed in fractionating shale oil is one based on temperature cuts. This method has been employed for two reasons: First, there is often only a small amount of oil available for study, in many cases less than 1,000 cc.; and, second, because many chemists hold that the present scale of gravities used for crude oil cuts is not applicable to shale oil, since it is thought that shale oil will yield a low gravity gasoline which will be equivalent to the higher gravity grades of gasoline used today for internal combustion engines.

The outline given below shows the cuts that are usually reported when this method of distillation is employed:

| | | | |
|---|---|---|---|
| Naptha, | that portion of the distillate with a B. P. | below | 150° C |
| Burning oil, | " " " " " " " | between | 150° C—200° C |
| Burning oil, | " " " " " " " | " | 200° C—250° C |
| Burning oil, | " " " " " " " | " | 250° C—300° C |
| Lubricating oil, | " " " " " " " | over | 300° C |

This method is undesirable, to say the least, especially since these end-points do not correspond to the end-points which are used in the distillation of crude oil.

The following method for the distillation of shale oil is suggested as one which is more valuable than the old method, in that the data obtained by this method can be approximately converted into terms of shale oil gasoline, naptha, kerosene, and gas oil after the shale oil standards have once been set. The method is as follows:

Place a 1000 cc. sample of shale oil in a 2000 cc. Pyrex, Engler distillation flask. Connect the outlet tube to a box condenser, the inner tube of which is surrounded by an ice pack.

Start the distillation with a low flame. First record the boiling point of the oil, then watch the distillate and replace the receiver for each 3 per cent cut collected; i. e., for each 30 cc. of distillate when a 1000 cc. sample is used. Care must be taken to record the end point of each fraction. Continue the distillation until a temperature of 300 degrees C. has been reached. (The residue from this distillation may be used for the paraffin determination.)

A careful record should be kept of the end point and gravity of each fraction, for from this record an estimate of the commercial products can be computed after the shale oil standards have been established.

When less than 1000 cc. of oil is available, it is necessary to make larger cuts than 3 per cent. However, the larger the percentage cut, the less valuable is the data.

If it is desired to report the commercial products obtained from the shale oil on a basis comparable with present crude oil products, an approximation can be made by grouping and redistilling the fractions from the above distillation on a basis of their end points. The following cuts are recommended for this purpose:

1. Naptha, with an end point of 425 degrees F. (Gasoline.)
2. Naptha, with an end point of 480 degrees F. (Naptha.)
3. Naptha, with an end point of 575 degrees F. (Kerosene.)
4. Gas oil, remainder of distillate.
5. Residue.

In the case of kerosene, the color, flash point, and flame test are more important than the end point, and consequently the standards which have been set for crude oil kerosene will probably be applicable to shale oil kerosene.

The paraffin content of the shale oil may be determined from the residue of the first distillation, as follows:[5]

Drain the ice water from the condenser and put a weighed receptacle in place. Heat the flask until all the oil has been driven over and the residue has coked completely. The heavy oil distillate thus obtained is analyzed for paraffin as follows, the amount of paraffin in the original oil being calculated from the amount in the distillate:

Five to 10 grams of the substance are dissolved at room temperature in a mixture of ether and absolute alcohol (1:1) to a clear solution, then cooled to —20 degrees C., just enough alcohol-ether mixture added till all oily drops are dissolved and only paraffin flakes are visible. With much paraffin, it is advisable to warm with ether to complete solution and then add the same volume of alcohol. The precipitated paraffin is then filtered on a funnel, surrounded with a rock-salt and ice-freezing mixture, all traces of the alcohol-ether solution being removed, and then washed free from oil by means of alcohol-either. The residue is then washed into a weighed glass dish with hot benzol or naptha and the solvent evaporated on a water bath. The paraffin is carefully washed with cooled alcohol-ether until 5 cc. of the filtrate on evaporation will give no residue, or only a trace of material solid at room temperatures, is obtained; too prolonged washing is to be avoided because of the still quite noticeable solubility of paraffin in alcohol-ether. If, on cooling, the paraffin is seen to be hard, it is heated at 105 degrees C. for 15 minutes and weighed after drying in a desiccator; if the paraffin is soft (with melting point under 45 degrees), it should be dried several hours in a vacuum desiccator at 50 degrees before weighing.[6]

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[5]Holde-Mueller: Examination of Hydrocarbon Oils and Saponifiable Fats, p. 37.

[6]The writer wishes to express his appreciation for the assistance and co-operation rendered by E. C. Carpenter, A. W. McCoy, L. C. Snider and L. E. Jackson of the Empire Gas and Fuel Company, and to Martin J. Gavin of the Bureau of Mines for suggestions and criticisms of the manuscript.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS

# STRATIGRAPHY AND STRUCTURE OF NORTHEASTERN NEW MEXICO

DAN L. GARRETT

## INTRODUCTION

The increasing interest of the oil man in New Mexico and the fact that there is little available literature on the northeastern part of this, the fourth largest State in the Union, makes desirable any contribution to our knowledge of this area.

The region which, in this paper, is included in northeastern New Mexico, is limited on the north and east by the State boundaries, on the south by 36 degrees N. latitude, and on the west by 105 degrees, 33 minutes W. longitude. It comprises an area of some twenty thousand square miles, about five times the size of the State of Connecticut.

## PHYSIOGRAPHY AND DRAINAGE

In a broad way, northeastern New Mexico is a great plain, rising rapidly to the west. In traveling from Clayton to Des Moines, about fifty-two miles, one does not realize that he rises some 1,500 feet, so uniform is the slope. The plain is broken in the southeast by the bluffs of the Llano Estacado and in the south by the "breaks" of the Canadian. Sierra Grande, an old lava plug, just southwest of Des Moines, is the highest peak east of the Rocky Mountains. West of the 104th meridian, the country slopes rather abruptly into the Canadian river valley. Thence, westward the land rises to the summit of the Rockies.

The area is drained by Canadian and Cimarron rivers and their tributaries. Canadian river rises near the Colorado line, in the neighborhood of Raton, flows south for a distance of 125 miles, and swerving suddenly to the east, maintains an east course into Texas. This course may be due to structural causes. A structural arch, which passes from near Watervale, Colorado, through Mills, New

Dan L. Garrett, San Antonio, Texas.

Mexico, bars the path of the Canadian to the eastward. The area drained by Cimarron river lies north of the Colorado and Southern Railroad. The river rises east of the fold mentioned and flows parallel to the Colorado line until it enters Oklahoma at Kenton.

## STRATIGRAPHY

The rocks of northeastern New Mexico are varied in character, including both igneous and sedimentary rocks that range in age from from Pre-Cambrian to Quaternary.

### PRE-CAMBRIAN

Granites make up the major portion of the mass of the Rockies. Schists and gneiss of various kinds outcrop at the eastern edge of the Rocky Mountains, and in the mountains northeast of Chico.

### PENNSYLVANIAN

*Magdalena Group*—Many hundred feet of massive limestone and intercalated shale beds in the region of Hot Springs, N. M., have been described in part and assigned to the Magdalena group by Lee and Girty.[1] For the most part, the limestone is dark gray to blue, on freshly exposed surfaces,and near the base is coarsely crystalline. The shales, a minor portion of the section, are dark gray to blue-black in color. The Magdalena group in this region rests unconformably on the pre-Cambrian schists and gneiss.

*Red-Beds*—Red sandstones, red shales, gypsum and salt of Pennsylvanian age are found at numerous places in the Rocky Mountain region. The deposition of red sediments began early in the Pennsylvanian and in a few instances continued without apparent break through Permian and Triassic times. In the region of Hot Springs there is a great thickness of this red series, the lower 200 feet of which, at least, has been placed in the Pennsylvanian.

### PERMIAN

*Red-Beds*—Red sandstones and shale, of Permian age, are widespread in northeastern New Mexico, and their great thickness will probably be the greatest obstacle to the oil and gas development of the region. Near Las Vegas they are nearly 3,000 feet thick.

[1] Lee and Girty, Manzano group—U. S. Geol. Survey, Bul. 389.

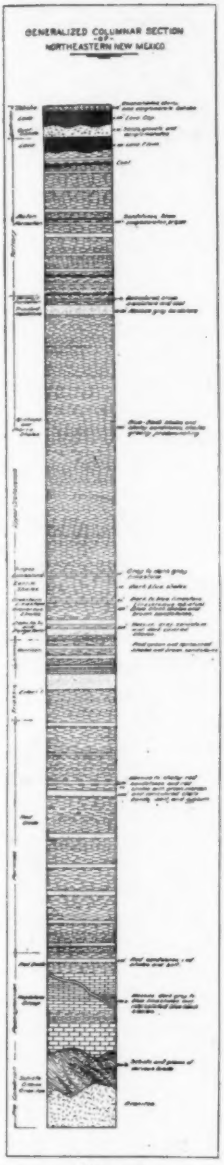


Figure 1

TRIASSIC

*Exter* (?)—Red and brown sandstones, with red and vari-colored shales of known Triassic age and probably equivalent to the Exter, overlie the Permian and outcrop along the eastern edge of the Rockies in the valley of the Cimarron, the Canadian, west of Logan and the Pecos. They also outcrop along the lower part of the bluffs of the Llano Estacado and the "breaks" of the Canadian. The exact thickness of the Trias in this region is not known, but together with the Permian, it varies from about 2,000 feet in Colorado[2] to approximately 3,000 feet at Las Vegas. Everywhere there is apparent conformity between the Permian and the Trias.

JURASSIC

*Morrison Formation*—The Jurassic is made up chiefly of green sandy shale and brown to gray sandstones. Its average thickness does not exceed 250 feet.

The Jurassic rests in apparent conformity on the Triassic, but on the Cimarron, between Kenton, Okla., and Folsom, N. M., evidence of unconformity between these series was observed. Near Johnson the lower Morrison sandstone rests horizontally upon red Triassic sandstone, which is inclined 10 degrees.

COMANCHEAN

*Purgatoire Formation*—A series of sandstones and shales, known as the Purgatoire formation, makes up the Comanchean in this region. The maximum thickness of the

[2]N. H. Darton, U. S. Geol. Survey, Bul. 691-A.

Purgatoire is found on Tucumcari Mountain, where it includes 30 feet of massive yellow sand stone overlain by 110 feet of yellow and blue shales, which contain abundant Gryphaeas. A sandstone, 90 feet thick, the Dakota, caps the mountain.

CRETACEOUS

*Dakota Sandstone*—The Dakota comprises massive to thin-bedded sandstones and black to buff-colored shales and yellow clays, which rest upon the Morrison, or Purgatoire, and beneath the Graneros shale.[a] The thickness of the series ranges from 225 to 275 feet. The massive sandstone portion of the Dakota has a thickness ranging from 60 to 90 feet. On freshly exposed surfaces, the sandstone is white to light yellow, but it weathers to a yellowish brown, with black blotches of iron. The Dakota sandstone is very widespread in northeastern New Mexico, being either at or near the surface over one-half of the entire area. It caps the escarpment at the "breaks" of the Canadian and forms the upper part of the canyons of both Canadian and Cimarron rivers. With the exception of a thin mantle of caliche, it also caps the Llano Estacado, southeast of Tucumcari.

*Graneros Shale*—The uppermost beds of the Dakota grade into the Graneros shale, which consists of about 150 feet of dark-colored shale and thinly bedded sandstones. The shale outcrops in the creek beds near Clayton and are to be found on the gentle slopes between the rim of the Canadian canyon, formed by the Dakota and the escarpment back from the canyon made by the Greenhorn limestone.

*Greenhorn Limestone*—This division consists of 40 to 50 feet of dark gray to blue limestones, characterized by the abundance of the pelecypod, *Inoceramus labiatus*.

*Carlile Shale*—The Carlile shale outcrops in the neighborhood of Springer and to the southwest. It is black and has a high bitumen content. The average thickness is 150 to 200 feet.

*Timpas Limestone*—This limestone, above the Carlile shale, forms the higher escarpments east and southwest of Springer. It is about 50 feet thick and consists of a series of gray limestones and calcareous shales.

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[a]T. W. Stanton—Apishapa Folio, No. 186.

*Apishapa and Pierre Shales*—These two shales together are approximately 2,500 feet thick. They are composed of alternating shales and sandstones, shale greatly predominating. They form the principal part of the Coal Mesa, which is a high escarpment, extending from the town of Cimarron northeast to Raton. More than 90 per cent. of New Mexico's coal is taken from the sides of this mesa.

*Trinidad Sandstone*—The Pierre shales grade upward into the Trinidad sandstone. This sandstone outcrops near the top of the Coal Mesa and varies in thickness from 75 to 100 feet.

*Vermejo Formation*—This series of dark-colored shales, brown sandstones and coal beds form the highest part of the Cretaceous section in this area. The thickness varies from 0 to 175 feet. They are overlain by the Raton formation of Tertiary age and have their type exposure in Vermejo Park, where they are exposed by a sharp arching of the strata.

### TERTIARY

*Raton Formation*—This formation forming the top of the Coal Mesa, is composed of sandstones, shales, conglomerates and coal, and overlies the Vermejo unconformably. The maximum thickness of this series exceeds 1,600 feet.

*Lava Flows*—Flows from Ocate crater on Turkey Mountain in the region west of Waggon Mound are probably of late Tertiary age. The lava flowing from Ocate Crater spread out over the country until the Mora River was reached. Here it partially filled the canyon and flowed down stream, to where the Mora joins Canadian river; thence down the Canadian for some distance before spreading out on the flats near Sabinosa. There is no way of telling the age of this flow, except by the amount of erosion that has taken place. This seems to be considerable from the fact that Mora river has cut a new canyon 400 feet deep in the lava. This represents a great amount of work and taking into consideration the time required to accomplish it, the flow may be referred to the Tertiary.

### QUATERNARY

The Quaternary in northeastern New Mexico consists of a variety of rocks, ranging in character from the caliche deposits capping

the Llano Estacado to the extensive lava flows in the north central part of the area.

*Sands, Gravels and Conglomerates* of the Quaternary age cover a large part of the Great Plains area. They also overlie the Dakota unconformably, and are in turn covered unconformably by the caliche deposits of the Staked Plains. There are also extensive sand, gravel and conglomerate beds in the region southeast of Chico. These cover the underlying Cretaceous strata for miles and make it a difficult task to locate definitely the axis of the Chico Uplift.

*Lava Flows*—Beginning probably in Tertiary time and continuing well through the Quaternary, the north central part of the area has experienced intense vulcanism. Many cubic miles of lava have welled up and flowed out over the surrounding country through numerous vents now represented by lava plugs and cinder cones. The highest mountain east of the Rockies, Sierra Grande, near Des Moines, is an old lava plug. Four miles northeast of Dedman is a very perfect cinder cone, about 900 feet high, Capulin Peak. The recent age of these flows is shown by the very slight change in lines of drainage since the flows, for old stream beds are shown clearly by tongues of lava extending many miles from the main sheet. One example of this is found in the Cimarron Canyon, some five miles east of Folsom, where there has been practically no erosion since the lava welled up out of the vent, flowed over the rim of the canyon and down the bed of the river for approximately four miles.

"*Caliche*"—An unconsolidated, chalky lime conglomerate known as caliche, covers practically the entire eastern half of northeastern New Mexico and caps the Llano Estacado. At present little is known of its origin. Some maintain that it was deposited by streams, and the fact that it contains numerous water-worn boulders and pebbles seems to substantiate this interpretation. However, Doctor Udden[4] has advanced the theory that it was formed by percolating ground waters carrying calcium carbonate in solution, which, coming to the surface, excessive evaporation caused the precipitation of lime, which has built up the caliche deposits. At several places near Clayton, N. M., this interesting deposit appears both above and below the lava cap.

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[4]Bul. 44, Bureau of Economic Geology and Technology, Austin, Texas.

## STRUCTURAL FEATURES

In general, the folding of the region resolves itself into one greater and one smaller geanticline, with many small folds along the flanks of each.

The larger of the two forms the Rocky Mountains and extends in a general north and south direction through New Mexico and Colorado. This fold is of little interest to the oil geologist, except that it represents a line of weakness along which great stresses and strains have found relief not only in heaving up the Rocky Mountain system, but in forming numerous anticlines and domes along its flanks. This great geanticline passes through and along the west border of the area under discussion.

The smaller of the two folds mentioned above has no name; the name Chico Uplift is here suggested. Its axis is roughly parallel with that of the Rockies and can be traced in a general north and south direction for some 150 miles. From Colorado[5] the axis enters New Mexico, southwest of Watervale, and passes in a southwest direction near Dedman to Chico, where it turns directly south. From here it passes through Mills, west of Roy, and disappears before reaching the town of Newkirk in Guadalupe county. The geanticline is almost directly west of Folsom, Union county, but its exact location is difficult to determine because of extensive lava flows that cover this region.

The maximum reversal of this fold was estimated as 3,000 feet. Dedman

[5]N. H. Darton, U. S. Geol. Survey, Bul., 691-A.

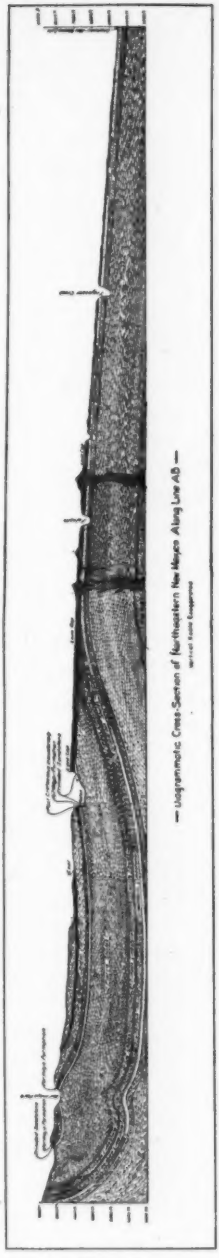

Figure 2

on the Santa Fe cutoff has an elevation of 6,650, while Otero on the Santa Fe main line and directly west of Dedman has an elevation of 6,387. Dedman is near the axis of the fold, only a few feet above the Dakota sandstone. Otero is near the bottom of the geosyncline, between the Chico and the Rocky Mountain Uplifts, and is within 500 feet of the top of the Pierre shale. Otero is thus 263 feet lower, with reference to sea level, and 2,760 feet higher stratigraphically than Dedman. This indicates a total west dip of about 3,000 feet. With a length of 150 miles and a maximum reversal of 3,000 feet, this geanticline is of no mean proportions and in size compares with the Cincinnati Arch and other well-known minor uplifts. If oil and gas are present in northeastern New Mexico, this arch is doubtless the principal factor in their accumulation. Unfortunately, the entire fold from Chico northward is covered by lava flows, which are in places 100 to 200 feet thick and crossed by numerous dikes and vents. This, of course, renders it more or less worthless as far as oil and gas production is concerned. However, the forces that caused this great arching of strata have formed smaller folds along the flanks of the major one. The writer knows of five in Union county. These smaller structures will probably produce any oil and gas which is found in northeast New Mexico.

### PROBLEMS OF DEVELOPMENT

*Depth of Wells*—Since no oil and gas will probably be found in large quantities in the Permo-Trias red-beds, the question at what depth the drill will pass through the red series into the Pennsylvanian, the horizon of possibilities is important. Record of only one well that has penetrated the red-beds in this region is available and it is necessary to refer to the outcrops along the Rockies for data as to thickness. West of Las Vegas, where the strata are inclined at an angle of 30 to 90 degrees, the thickness of the red-beds appears to be at least 3,000 feet. Since the Permian sea encroached from the south, this thickness, if not reduced by pre-Permian erosion, should remain more or less constant in an east and west line. This would give the Red-Beds series in the Canadian river valley a thickness of between 2,500 and 3,000 feet, as the drill must start some 200 to 400 feet below the top of the Trias. A fair test though should go 3,500 or 4,000 feet.

A recently secured log of the McGee well, ten miles southeast of Tucumcari, Section 27, T. 10 N., R. 31 E., shows that five feet of salt was encountered at 2,372 feet, and the drill passed into "black and gray lime with shale partings saturated with oil" at 2,375 feet. This appears to determine the thickness of the red series in the southern part of the area under discussion.

The depth to the Pennsylvanian on the Mesa, the area above the "breaks" of the Canadian and underlain by the Dakota sandstone, is, of course, greater. Darton[6] has reported a thickness of 2,000 feet for the red beds in southeastern Colorado. This suggests that the Permian, which probably constitutes by far the major portion of the Red Beds is thinning out to the north. This is also to be expected because this area was covered by the Permian sea for a much shorter period than the area farther south. It may be presumed that the thickness of the Red-Beds in the Mesa region does not exceed 2,500 feet. This thickness, plus 500 feet of Juras and Cretaceous, would give a drilling depth of 3,000 feet before the drill will reach the zone of possible production. In this region a fair test should go 4,000 feet.

### ACCESSIBILITY

An important factor in development is the accessibility of the area. Where it is necessary to transport materials a great distance overland, the price of operation is greatly increased. One company in northeastern New Mexico has transported everything required for operation a distance of fifty-five miles. There are areas with promising structure, however, that are within a distance of fifteen miles from railroad.

*Fuel and Water*—These are minor problems that must be solved by the individual operator. Usually good water is scarce at the surface, but shallow wells in most cases produce a sufficient supply, especially where the Dakota is near the surface.

### SUMMARY OF DEVELOPMENT

There has been little development in northeastern New Mexico. A number of wells are drilling, but like most wildcats, exact informa-

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[6]N. H. Darton, U. S. Geol. Survey, Bul. 691-A.

tion in regard to depth is difficult to secure. Below are the drilling wells, their locations and approximate depths.

| NAME | LOCATION | DEPTH |
|---|---|---|
| United Oil & Gas Co. | Sec. 6, T. 31 N., R. 33 E. | 2500 feet |
| McGee, *et al* | Sec. 27, T. 10 N., R. 31 E. | 3200 feet |
| Ute Creek Well | Sec. 32, T. 20 N., R. 31 E. | 1500 feet |
| Snorty Gobbler Oil & Gas Co. | Sec. 35, T. 28 N., R. 31 E. | —— |
| Reed Bros. & Co. | Sec. 35, T. 13 N., R. 35 E. | —— |
| Bryantine Well | Sec. 25, T. 15 N., R. 35 E. | —— |

This paper is presented with the permission of Dorsey Hager and A. Redmond Robitaille. The writer wishes to acknowledge assistance of Dr. Douglas R. Semmes, University of Alabama.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS

# SUGGESTIONS OF A NEW METHOD OF MAKING UNDERGROUND OBSERVATIONS

J. A. UDDEN

In the north-central part of the State of Texas, where wells are being drilled to the depth of 4,000 feet and more in order to penetrate the Bend formation (Pennsylvanian), which is the chief oil-bearing horizon in that part of the State, it has been found that the structure of the Bend and that of the underlying Ellenburger limestone (Ordovician) is quite generally the same. The plotting of underground structure by drillers' logs or by observations on cuttings from the Bend is very difficult, for the reason that there are small variations in the rocks of the Bend, not only vertically but also horizontally, and that these small variations lie near the limit between shale and limestone. Whether a certain part of the formation is reported as shale or as limestone will in large part depend upon the judgment and experience of the driller, or other observer. It has been exceedingly difficult to trace a definite horizon in the Bend with any considerable certainty. Exposures of the Bend indicate also that there are horizontal changes in this formation. For those who use drillers' logs in the making of structural maps, it has been found expedient to use the contact of the Bend and the underlying Ellenburger as the key horizon. Contours are drawn on the upper surface of the Ellenburger.

The top of the Ellenburger is a plane marking the greatest change of all the sediments in this part of the State. The Ellenburger itself is about 1,000 feet thick, where it is present in its full development, and almost all of this is one solid limestone. The Bend, which overlies it, is, as already stated, quite variable in its composition. In the San Saba country it has considerable limestone. West from here it becomes more and more shaly, and the same change is noticeable in a northerly direction, at least at some points. The Bend is overlain by the Strawn, Canyon and Cisco divisions of the Pennsylvanian. These consist largely of shale with some sandstones and

Dr. J. A. Udden, Director, Bureau of Economic Geology and Technology, Austin, Texas.

limestones, and may collectively be characterized as much less uniform in composition than the Ellenburger. In the course of development in the Ranger-Desdemona field and other fields in this part of the State, it has become evident that the structure of the Bend does not always parallel the structures in the outcropping rocks and that therefore the prospecting of the Bend by the common geologic methods is not entirely satisfactory.

It has suggested itself to the writer that it ought to be possible, with present refinements in physical apparatus and their use, to construct an instrument that would record the reflections of earth waves started at the surface, as they encounter such a well-marked plane of difference in hardness and elasticity as that separating the Bend and the Ellenburger formations.

Some such instrument as a seismograph, especially constructed to be sensitive to vertical waves, possibly a slight adaptation of some of the present seismographs would be amply suitable for the purpose. A seismic wave might be started by an explosion at the surface of the earth, and a record of the emerged reflection of this wave from the upper surface of the Ellenburger limestone might be registered on an instrument placed at some distance from the point of explosion. The record would, of course, be a component of the direct and the reflected waves. It ought to be possible to notice the point at which the first reflection from the Ellenburger appears on a continuous record. The time of the record being known, it ought to be possible to figure the depth to the plane of reflection.

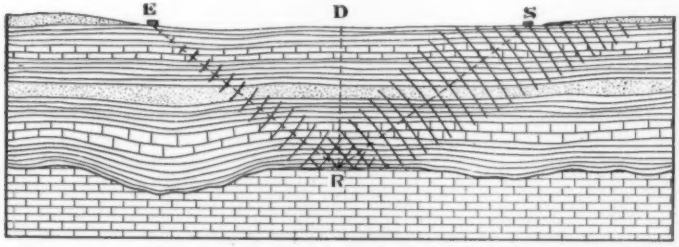


FIGURE 1. Reflection of earth waves, started at surface, from the contact between the Bend formation and the underlying Ellenburger limestone. E, point of explosion; S, position of seismograph; R, point of reflection of earth wave; RD, depth from surface to Ellenburger limestone.

It seems to me that by the making of a number of observations at points where the distance to the upper surface of the Ellenburger is known, it would be possible to learn to interpret the record correctly. It might be found necessary to make new adaptations on the working parts of the instrument. The difficulties ought not to be insurmountable. After these are once mastered, observations could be made anywhere, probably with quite rapid progress, and the entire upper surface of the Ellenburger might be mapped over wide areas with relatively small effort. The topography of the Ellenburger could, so to speak, be contoured directly by any number of observations desired. With such a topographic map of the surface of the Ellenburger, it seems to me that millions of dollars' worth of drilling could be eliminated, which will otherwise have to be done before all of the pools in the Bend shall have been located.

Why not pay twenty thousand dollars for "theoretical" experiments, if by so doing a million in expenses on "practical" work can be saved?

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS

# PETROLEUM INVESTIGATIONS IN SWITZERLAND

EDWARD BLOESCH

Only within the last few years has it been realized how widely distributed a substance petroleum is, and that it is present in various sedimentary series and in many different parts of the world. In most places it requires close investigation and considerable testing, however, to determine whether the crude oil is present in commercial quantities or not.

When the war broke out in 1914, Switzerland experienced a shortage of petroleum products, which reached a critical stage after Roumania joined in the fight. Large business interests, headed by Sulzer Brothers, known as manufacturers of Diesel engines in Switzerland and in the United States decided to investigate the possibilities of producing oil in Switzerland. The geological work was done largely by Arnold Heim and later published by the Swiss Geological Survey[1].

Geologically, Switzerland is divided into three provinces. (1) The Alps, in the southern part are famous for their large overthrusts. (2) In the northwestern part, the Jura Mountains, really a branch of the Alpine folding, show more moderate structure, resembling that of the Arbuckle Mountains in Oklahoma. (3) Between these two mountain ranges there is a Tertiary basin, largely covered by glacial deposits. This basin is about forty miles wide in the center of the country and narrows to about ten miles near Geneva.

The investigations for petroleum were made in the Tertiary basin along the front of the Jura Mountains, where oil seepages, and in one place a gas vent, had been known for some time. Natural exposures and shallow excavations revealed good oil sands in this zone, which showed an oil content of as much as 19 per cent. of the volume of the sand. Some of these oil sands are sufficiently rich that it would pay to mine them and produce the oil by distillation if the

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Edward Bloesch, Okmulgee, Okla.

[1]Arnold Heim and Adolf Hartmann: Untersuchungen uber di· petrolfuhrende Molasse der Schweiz, Beitrage zur Geologie der Schweiz Geotechnische Serie, 6, 1919.

price of the products remained at the level attained during the war. The oil is of a paraffine base, high in lubricants, but low in gasoline, as is to be expected just at the surface. The oil sands are all nearly in the same stratigraphic horizon, lower Aquitanian (Upper Oligocene).

Important is the observation that at least some of the oil was formed in place; that is, that these particular sand strata originally contained the organic matter from which the oil was formed. This is proven by thin layers of oil sand alternating with barren beds of exactly the same texture and porosity with no shale partings between. Oil shales from which the oil might have migrated to the sands have not been observed. This indicates that the oil might not be concentrated and accumulated as is desirable for good production.

A study of the structure of the territory revealed a series of broad, well developed anticlines in the Tertiary, along the Jura Mountains. The flanks of the anticlines dip generally from 5 to 20 degrees, but are occasionally much steeper. Unfortunately, some of the anticlines show no doming, while others are already eroded at the apex down to the oil sand or even to the underlying Cretaceous. The best developed anticlines are some distance from the place where the richest oil sands have been found at the surface.

The investigations show that while considerable oil is present in this territory, drilling will have to decide if it is present in commercial quantities. It was decided to drill several tests at once, as the country needed oil very badly. Unfortunately, however, during the war no drilling machinery could be obtained. Since the prices on petroleum products have been reduced, nothing more has been done, as it seems easier to import than to take the considerable risk of drilling. The present rising oil market will soon change the situation and some day the drill will furnish more information. Then it may be hoped that Switzerland will be added to the list of oil-producing countries.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS

# THE ORIGIN OF THE CENTRAL KANSAS OIL DOMES

ELIOT BLACKWELDER

During the past year the writer has studied some of the oil-bearing structures of Central Kansas and Northern Oklahoma. For the sake of comparison, he has learned what he could regarding others from consultation with other geologists and from published papers. The conclusions thus reached, although in no sense novel, seem to further our understanding of the origin of these domes.

## SIGNIFICANT FACTS OF OBSERVATION

The typical structure of the region is not the elongated anticline, but the round or elliptical dome of relatively small dimensions. The domes are sprinkled somewhat thickly over the east limb of the shallow syncline of the Great Plains. In a few instances they are associated in one or more definite systems, as along the Elmdale-Eldorado line, but for the greater part of the district the detection of such a system or alignment requires a vivid and conscienceless imagination. Owing to the fact that these domes are usually so flat that they cannot be discovered without rather precise altitude measurements of suitable rock ledges, it sometimes happens that a series of domes has been mapped along the outcrop of a certain well-defined limestone, whereas in the intervening broad shale outcrops the structure has not yet been worked out. This produces a specious alignment which is well exemplified by the series of prominent domes recently mapped along the outcrop of the Herington and Winfield limestones from Central Kansas, south to Kay county, Oklahoma.

The slopes of the domes as mapped at the surface are very gentle, ranging from one to about ninty feet per mile. The average is less than fifty feet per mile, or about half of one degree. In form they are roughly circular or short and elliptical and comparatively regular in outline. A few have subsidiary lobes, but the majority, especially of the smaller ones, have not. Associated with these bulges there

Eliot Blackwelder, Denver, Colorado.

are occasional saucer-like basins, or "counter domes," of about the same slopes and dimensions. In general these structures average about one to three miles in longest diameter, but some of them are much less than one mile and a few of them, like the Eldorado dome, are as much as ten to fifteen miles long.

In some parts of the region normal faults are rather common, whereas in others scarcely any faults have been detected, although good outcrops afford ample opportunities. In those districts where faulting is prevalent most of the faults are roughly parallel in a direction usually west of north; and, in the majority of cases the upthrown side is on the northeast. There seems to be no detectable relation between the faults and the domes, for the former cut across the latter indiscriminately. In no case has the writer found a dome with radial or peripheral faults.

In the Augusta, Cushing and Eldorado domes, and in nearly all others that have been thoroughly drilled, the fact is revealed that the deeper formations are more steeply inclined than those above. In other words, the formations become thinner radially toward the center of the dome. Also a close study of the logs indicates that this thinning is confined largely to the shales.

Any theory of origin of these domes, in order to be entitled even to temporary consideration, must successfully account for the facts above mentioned. There may be other essential characteristics.

### EXPLANATIONS WHICH HAVE BEEN SUGGESTED

*Tangential Compression*—It is quite natural that lateral compression should be the first cause to suggest itself when we are considering folds of any kind. It is a predisposition inherited from our college courses. Nevertheless we are all aware that some folds are of other origins. If one compares the type of folds usually produced by lateral compression with those observed in the Kansas region he finds comparatively little in common between them.

Lateral thrust usually crumples the beds in long, comparatively narrow folds arranged in winding systems. Even where, on account of torsional movement, the folds are short and elliptical in shape, they are generally arranged in definite series *en echelon*. Again, this process forms not only many small folds, but almost invariably many of rather large dimensions, i. e., ten to one hundred miles long, and five to fifty miles wide. It seems to be established, by the work

of R. T. Chamberlin[1], that folds of small dimensions are particularly characteristic of regions where only a thin shell has been deformed, resulting in rather close crumpling, steep dips, and overthrusts (Appalachian type), whereas the deformation of a thick shell produces broad folds with relatively gentle dips (Colorado-Wyoming type).

The radial convergence of beds, which is one of the noteworthy features of the Kansas-Oklahoma domes, seems inexplicable on the lateral compression theory. If the beds had been *strongly* folded the shales might have yielded by flowage, although the shale formations would then be thinner on the limbs and thicker on the crest. The observed fact is, however, that pieces of shale ejected from wells do not show the finely crenulated bedding which is the normal result of flowage, and still more decisive is the fact that the beds are not thickened on the crest but are thinner. On the other hand, with folding so exceedingly gentle as has actually occurred in this region, there could be no appreciable flowage and hence no detectable convergence in the shale from that cause.

*Vertical Readjustment Due to Deep-Seated Rock-Flowage*—This hypothesis was evidently adopted in order to avoid the fatal difficulties inherent in the theory of tangential compression. While it does that successfully, it appears to have serious weaknesses of its own.

Although the entire subject of isostasy is not yet established on a firm and satisfactory basis of agreement, most of us will probably admit that there is such a thing as isostatic balance in the earth and that it is maintained by readjustments which have at least a vertical component. The best evidence available, however, seems to indicate that these readjustments affect only rather large masses of the earth's crust, such as broad plateaus, geosynclines, or larger units. There is abundant evidence to indicate that such movements do not appreciably affect small areas, such as individual mountains, hills, valleys, etc. Yet, unless these vertical isostatic adjustments have caused the raising and lowering of areas only one-quarter to two miles in diameter to heights or depths exceeding one hundred feet, they need not be seriously regarded as causes of the Kansas domes and hollows. Although this is an admittedly theoretical question, subject to arguments on both sides and under present

[1] R. T. Chamberlin, Journal of Geology, Vol. 27, 1919.

circumstances incapable of definite solution, the hypothesis seems, for the reason given, to offer but little promise.

*Uneven Condensation of Deposits*—A third hypothesis has been suggested by several students of the question and now has many advocates.[2] The underlying thought in this view is the known fact that sediments are more or less compressed vertically by, and proportionately to, the weight of the overlying beds, and that this condensation is different in amount among clays, sands, and other types of sediments.

Of this main idea there are several off-shoots. The settling may have taken place more or less uniformly, but over a hilly or mountainous foundation, thus giving rise to domes on hilltops. Again, since condensation affects mud and silt much more than sand, a formation containing thick lenses of sand would be compressed unevenly in different parts, thus giving rise to differences in the otherwise uniform dip of surface formations. This is a distinction which has important consequences, but probably most of us will admit that both conditions exist and are factors worth considering.

In actual effect on the result, the sand lenses seem much less important than the basal hills and mountains. In the first place, most sand lenses have very gentle slopes and could not therefore account for any but the weakest domes. In the second place drilling has shown that on some of the more pronounced domes individual sands are comparatively uniform throughout the structure or even diminish regularly from one side to the other. Therefore, while the relatively incompressible sand lens is undoubtedly a factor, the writer has become convinced that it is generally a trivial one.

In judging the other form of this explanation of the domes, i.e., the irregular settling of deposits upon a hilly foundation, it is necessary to inquire also whether it is quantitatively competent to produce the observed features, and secondly, whether the Kansas domes have actually been made in this way. Finally, if there are any positive objections to the theory they must have careful attention.

Experimental evidence would be the most valuable, but unfortunately it is thus far rather scanty. Although several of us have

[2] The writer has recently learned that a paper on this subject was read by Dr. M. G. Mehl, of the University of Missouri, at the St. Louis meeting of the American Association for the Advancement of Science last winter, and through the kindness of the author has been privileged to see it in manuscript.

doubtless planned such experiments, and Doctor Mehl states that he is even now at work on them, no one seems yet to have made a consistent series of determinations of the ratio of condensation of different kinds of sediments under different loads, nor do we know the value of the time factor in this process. In a general way, however, enough has been done to show that clean sand, calcareous reef-rock, etc., resist compression very effectively at ordinary loads, whereas silt, clay, peat and especially organic slimes, are condensed to notable degrees, in some cases largely exceeding fifty per cent of the original volume. The common occurrence of crushed shells in bituminous shale as compared with their absence in sand and gravel beds is an instance of such evidence.

In the absence of quantitative experimental data, the writer had recourse to calculations based on certain assumptions that appeared reasonable. For example, taking a typical log of the Eldorado field and allowing two per cent of condensation in the sands, five per cent in the limestones, and fifteen to thirty-five per cent in the shales, the average settling of the mass was estimated at twenty-three per cent. On this basis it would appear to require a pre-Pennsylvanian hill or mountain seven hundred feet high to produce the Eldorado dome, which has a surface structural relief of about one hundred sixty feet. It also readily accounts for the maximum dips on this unusually pronounced dome. Clearly this is not straining the probabilities far, inasmuch as drilling has shown that the buried granite range of this part of Kansas has a maximum relief several times as great as the hills above calculated. Many other calculations have been made with variations in the factors, but their general import is to indicate the entire competence of condensation as a cause of the domes.

In connection with this explanation, it is also necessary to inquire whether the various observed features of the domes agree with the theory. The dips should be very gentle, seldom over one or two degrees, and they should increase slightly in the deeper formations, because the condensation would be greatest where the beds are thickest. The beds of shale, especially at considerable depths, should thin somewhat toward the centers of the domes, but there should be very little change of this kind in the limestones or sandstones. There should be no regular system of folds, except where the topographic features of the old land were arranged in systems,

as in the Appalachian region today. In the former case domes should be the prevailing type of stracture, and in the latter case elongated anticlines. Drilling should reveal buried hills of pre-Pennsylvanian hard rock, such as chert or granite, in the central part of each dome, provided the bottom of the Pennsylvanian system is reached.

On reviewing these requirements it will be seen that all of them in greater or less degree are known to be characteristic of the Kansas field. Roundish forms and lack of systematic alignment are the rule. Radial convergence in the shales is common and is most marked in the higher domes. Dips are invariably gentle. Some of the domes that have been deeply drilled contain cores of granite or Paleozoic limestone.

Definite evidence against the hypothesis of differential settling of the sediments has not come to the writer's attention; but if any has been noted he trusts it will be brought out in the discussion at this time.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS

# GEOLOGY OF NEW MEXICO AS AN INDEX TO PROBABLE OIL RESOURCES[1]

JOHN K. KNOX

## INTRODUCTION

The interior of the United States, west of Mississippi river, is commonly divided into three great, major topographic provinces, the Great Plains, the Cordillera, and the High Plateau. Each of these provinces has a type of topography characteristic of it and very different from the topography of the other provinces. The Great Plains are level or rolling; the Cordillera is a tangled mass of high mountains; the High Plateau is a tableland, which might be described as the "land of mesas."

Each of the three major provinces is represented in New Mexico. The State is divided into three sub-equal parts by Rio Grande and Pecos rivers, and these three areal subdivisions correspond roughly with the topographic subdivisions. East of the Pecos are the Great Plains; between the Pecos and Rio Grande, and extending into the southwest corner of the State, is the Cordilleran area; west of the Rio Grande is the High Plateau.

Just as the three great provinces are distinct topographically, so they are distinct geologically both in stratigraphy and structure. In the Great Plains region of New Mexico a thin covering of Tertiary formations unconformably overlies beds of early Mesozoic and Paleozoic age. The Tertiary formations lie nearly flat and the subjacent beds normally dip gently eastward from the Cordillera into the great syncline which runs north and south through western Texas. This region may be divided conveniently into three districts, (1) an area in northeastern New Mexico where the surface formations are Tertiary or Cretaceous; (2) the area around Santa Rosa and Tucumcari, and in the Pecos Valley, where most of the surface formations are Permian or Triassic; and (3) the Llano Estacado where the surficial beds are Tertiary.

John K. Knox, Houston, Texas.

[1]This paper contains only the conclusions arrived at in a much longer paper just written on the same subject. The paper is based on the results of about one years personal work in New Mexico.

The rocks outcropping in the Cordilleran area range in age from pre-Cambrian to Tertiary, but Pennsylvanian formations probably are most widespread. The beds are much folded and faulted and stand at angles ranging from a few degrees to more than ninety degrees from horizontal. The Cordilleran region is divided conveniently into two parts: (1) the area of high mountains north of the Santa Fe Railway, and (2) the area of lower fault-block mountains between the Santa Fe Railway and the southern State boundary.

The High Plateau is underlain by a great thickness of nearly horizontal strata ranging in age from Tertiary to Pennsylvanian. Streams have cut deep gorges across the Plateau and have dissected it into a net work of mesas of widely differing area and height. The Plateau is more nearly a unit geologically than is either of the other major areas, but it may be divided conveniently into two parts, the San Juan Basin in the north and the Magdalena district in the south.

### NORTHEASTERN NEW MEXICO

The Tertiary formations of the Great Plains, consisting of poorly cemented sand, clay and gravel, outcrop over much of eastern Union county. It is not known with certainty what formations underlie the Tertiary in this region. One hundred miles to the southeast on Canadian river in the Texas Panhandle, similar Tertiary rocks overlie Triassic and Permian. In western Union county the Dakota sandstone appears from under the Tertiary which lies unconformably upon it, but we do not know how far east the Dakota extends under its Tertiary cover. This is not of great importance, however, as the Dakota is not an oil-bearing horizon.

The Tertiary area in northeastern New Mexico is not of great interest to the oil producer. There are no dependable evidences of structure favorable for the accumulation of oil in the pre-Tertiary formations, no individual bed in the Tertiary is traceable over any considerable distance, mapping on the Tertiary beds is very unsatisfactory, and the region is much disturbed by igneous intrusions.

West of the Tertiary area in Union county, the Dakota and Purgatoire sandstones outcrop over a large tract in Union, Colfax, Mora, and San Miguel counties. These rocks have been deformed and folded and at least one anticline of considerable size is present. In spite of these facts the area where they outcrop is not very attractive as a prospective oil field. On account of the massive

and uniform character of the sandstone beds and the very pronounced cross-bedding, it is not possible to recognize any one horizon in different places. Very careful and detailed instrument work may succeed locally, but over most of the area mapping of minor structures on the larger folds is impracticable.

Even more important than the character of the Dakota is the lithology of the underlying formations in which oil would be expected. If we accept 4,000 feet as being about the greatest depth to which a well can be drilled profitably at the present time, there is but little chance of finding valuable petroleum deposits by drilling in the areas in northeastern New Mexico where the Dakota and Purgatoire sandstones appear at the surface, because the 4,000 feet of beds immediately underlying the Dakota do not offer much chance of production. A number of wells have been drilled, and some are being drilled now, in the neighborhood of Des Moines, but up to the present none of them have shown signs of commercial production.

When examining any structure in northeastern New Mexico with oil development in view, it is very necessary to make sure that the structural form is not caused by an igneous body of the laccolithic type. Certain determination of this condition is not always possible, but the possibility must be given greater weight when evaluating a structure in this region. If the laccolith is deeply enough buried and has not pierced the productive oil horizons, oil will collect on the structure if other conditions are right, and the fact that a structure is of laccolithic origin need not necessarily condemn it as a possible producer of oil. In this region, however, the chances are that if a laccolithic structure is sufficiently marked to be determinable as a structure, the igneous rock is probably so close to the surface as to make the likelihood of obtaining oil very remote.

West of the outcrop of Dakota sandstone younger Cretaceous formations are exposed in a broad belt in the valley of Canadian river. This Cretaceous area, sometimes spoken of as the "Raton Field," is the most promising area for future oil production in northeastern New Mexico.

The plain of the Canadian river valley is underlain by the great shale series of the Upper Cretaceous, which includes beds ranging in age from Dakota to Pierre. The shale of the Benton and Pierre groups is of the type which commonly produces oil, and it is probable that a well drilled into these shales at almost any point would show

traces of oil. In Wyoming where the same formations have an almost identical appearance and composition, they produce vast quantities of oil.

Unfortunately, a careful search of the Cretaceous section in the Canadian Valley, from the top of the Pierre to the base of the Benton, has failed to show a single bed of sandstone which could be counted on to act as a reservoir for the oil produced by the Benton and Pierre shale. It is possible that lenses of sand are present in the section in places, but no such lenses are known to outcrop. The only reservoir horizons in the Cretaceous section in this district appear to be the Timpas and the Greenhorn limestones. In these formations the limestone is thin-bedded and the individual beds of limestone are separated by thin beds of more or less impervious shale. Such a lithologic condition does not produce a good oil-sand, but it does not make the storing of oil impossible, and oil may be present in these limestones somewhere in the district. It should be noted that nowhere along their outcrop, so far as observed by the writer, do these limestones show any traces of oil or gas, and although this does not prove that they are barren everywhere, they are barren over considerable areas.

In the absence of good reservoir horizons, it becomes of the utmost importance that any well drilled be situated on a very favorable structure in order that it may have some chance of success, but the absence of sandy horizons in the shale makes it very difficult indeed to detect such structures. In most places the surface is mantled by from two to twenty feet of weathered shale or river deposits which yield no information concerning the subjacent structures, and even where the unweathered shale is exposed, no definite beds can be traced from place to place. If the structure of the Canadian Valley is to be investigated, it can be done only by the expensive and tedious method of digging pits through the gravel and weathered surface material down to the unweathered shale, and there measuring the strike and dip. The Cretaceous area in the valley of Canadian river is the most promising territory for oil in northeastern New Mexico, but even it does not offer very rosy prospects of becoming an important producer.

The Raton Mesa district, west of the Canadian Valley, is underlain by Tertiary formations which are not likely to produce petroleum. Beneath the Tertiary, and overlying the Pierre shale, are 525 feet of

sandstone and shale belonging to the Trinidad and Vermejo formations which are Cretaceous in age and younger than the Pierre. The Trinidad sandstone is 100 feet thick and lies immediately on top of the Pierre, so it is not improbable that oil which may have originated in the Pierre shale might, under favorable structural conditions, collect in this sandstone. There is no very competent bed of impervious rock above the sandstone, however, and it is more than likely that any petroleum which may have migrated to the sandstone has already escaped. A well to test the Trinidad would be justified, however, if placed on an especially favorable structure.

Large anticlinal structures bring Cretaceous rocks to the surface in a number of places in the Raton Mesa district. Vermejo Park, which is probably the best known of these, is a large and well-defined anticline, and would be a very attractive drilling site were it not for the doubt as to presence of reservoir horizons in the Cretaceous formations underlying it. Structurally it is satisfactory, and it is probably the best place in which to test the Cretaceous formations of the district if any company is willing to drill such a test in face of the unfavorable lithologic conditions. A well 3,500 feet deep would afford a good test of the Cretaceous.

### SANTA ROSA-TUCUMCARI REGION

Throughout the Santa Rosa-Tucumcari region the surface formations belong to the great "Red Bed" series of central New Mexico. No part of this district has been studied in detail geologically, and the exact age of many of the formations is not known. The Dakota-Purgatoire sandstone at the base of the Cretaceous, and the underlying Morrison shale, are readily recognizable, and the boundary between them and the subjacent formations has been traced with fair accuracy. The 4,000 feet of sediments immediately underlying the Morrison belong to the Triassic, Permian, and Pennsylvanian systems. The Magdalena limestone at the base is definitely known to be Pennsylvanian, but on account of the paucity of fossils the upper beds are not readily classifiable as to age.

A massive sandstone, for which the writer proposes the name, Pecos Canyon, divides the red beds which overlie the Magdalena into two groups, (1) the upper "Red Beds", and (2) the lower "Red Beds." The upper "Red Beds" are probably Triassic; the lower "Red Beds" are Permian or Pennsylvanian or both.

Lithologically, the "Red Beds" are unpromising as a source of petoleum. Nowhere in the series is there any appreciable thickness of marine shale or other bituminous, oil-forming lithologic type, and, except in one locality a short distance north of Santa Rosa, no evidence of the presence of petroleum in the sandstones is to be seen.

Favorable looking structures are plentiful in all the Santa Rosa-Tucumcari region, and on account of the similarity of the formations and of the surficial conditions to formations and conditions at Burkburnett, operators have devoted much attention to the district within the past year.

During the year 1919 a well was drilled on Los Estaritos dome in T. 11 N., Rs. 18 and 19 E. Judging from surface indications this dome is almost perfect. It is regular in shape, is of good size, has ample closure, and should contain oil if oil is present in the district. The well spudded in, in "Red Beds" and drilled through "Red Beds" until it passed into granite between 1,900 and 2,000 feet without finding any oil. This well brought out two significant points, (1) that the Magdalena limestone is not present on Los Estaritos dome, although it is 1,800 feet thick, only thirty-five miles to the northwest; and (2) that the domal structure possibly owes its origin to renewed movement along an old line of granite hills which are now concealed by only a few thousand feet of Paleozoic sediments.

The presence of granite under Los Estaritos dome at the comparatively shallow depth of 1,900 feet suggests that many, if not all, of the numerous structures lying between the Sangre de Cristo foothills and the Texas line may owe their origin to renewed movement along an old line of mountains, and that they may be as barren of oil as Los Estaritos. It is worthy of note that the folds which are producing gas in the Texas Panhandle, due east of Santa Rosa, have a general east-west elongation, and some geologists suggest that a range of eroded and buried mountains extends from the Sangre de Cristo into Texas.

In view of the non-petroliferous character of the lower and upper "Red Beds", the probable absence of the Magdalena limestone from much of the disturbed area east of Los Estaritos dome, the non-bituminous character of the Magdalena even where found, and probability that the observed anticlinal structures in this district are underlain at shallow depths by granite or very old metamorphic

rocks, the "Red Beds" area in the Santa Rosa-Tucumcari regions is not an attractive oil prospect.

### THE LOWER PECOS VALLEY

Oil in less than commercial quantities has been found for many year in shallow wells in the Pecos Valley between Roswell and Carlsbad. The central part of the valley is floored by a thick mantle of Quaternary river deposits, flanked on the east by "Red Beds" and on the west by porous limestone of Permian age. The "Red Beds" are so unfossiliferous that certain determination of their age is difficult, but some part of the series is Permian, and part is possibly Triassic. Under the "Red Beds" is an immensely thick series of Pennsylvanian and Permian limestone.

The regional dip of the sedimentary series is to the east, decreasing from more than ten degrees at the crest of the Sacramento Mountains to nearly zero on the plains. Small anticlinal folds are not plentiful where the consolidated rocks can be studied on the long slope from the mountains to the Pecos, and in the central part of the valley, floored by Quaternary formations, it is not possible to determine by surface indications whether such structures exist or not.

A considerable number of wells have been drilled in the Pecos Valley during the past fifteen years, and although none of them have been commercially profitable, enough oil has been found to keep hope alive, and interest and drilling still continues. The wide area west of the Pecos where limestone is the surface formation is unpromising territory, because any oil that may have been in the limestone has probably escaped, and the limestone itself is so thick that it cannot be pierced. The area mantled by Quaternary deposits is very difficult prospecting ground, and apparently most past drilling has been done blindly. Old methods can probably be improved on, however, for a careful study of the logs of the numerous water wells that have been drilled in the valley should make possible a fairly close approximation to the sub-surface structure.

A favorable structure can be more easily located in the "Red Beds" area east of the river, and a good looking structure in this district would certainly be worth a test. The present small production is obtained from porous beds in the upper part of the limestone series which underlies the "Red Beds," and if even a small production could be maintained it would be profitable, as the wells are shallow, and

inexpensive to drill. Oil is a widely distributed mineral, however, and nothing so far found proves that commercial deposits of it are present in the Pecos Valley.

### THE LLANO ESTACADO

The surface formations of the Llano Estacado are Tertiary in age, and beneath them lie the Triassic, Permian, and Pennsylvanian beds which outcrop to the east and west of the Staked Plains. The continuity of the older rocks is fairly well established, because Triassic and Permian formations are exposed in the valley of Canadian river where it cuts across the Plains north of Amarillo, and formations thought to be Pennsylvanian have been encountered in wells drilled a few miles north of that city. Under all that part of the Llano Estacado which lies in New Mexico, the older formations dip eastward toward the axis of a great geosyncline, whose axis runs approximately north and south across the High Plains of the Texas Panhandle.

The surface of the Llano Estacado is a depositional surface on which no evidence of pre-Tertiary folding can be seen, and the Tertiary formations are not of such a character as to lend themselves to good structure mapping. Some detailed instrument work has been done on the "Cap Rock" and caliche horizons in the Tertiary, but at best this work is not very convincing or very satisfactory.

There is no reason to suppose that oil will be found in the Tertiary deposits themselves, and before drilling is undertaken in an effort to discover sub-Tertiary structures, it should at least be known that the sub-Tertiary formations contain oil. Nothing indicating the possibility of commercial production from these beds has yet been found, and at the present time the Llano Estacado must be regarded as one of the least favorable regions in New Mexico in which to prospect for oil.

### THE HIGH CORDILLERA

The High Cordilleran area of New Mexico includes the territory lying between the main line of the Santa Fe Railway and the Colorado State line from the longitude of Las Vegas west nearly to the Rio Grande. It is an area of high mountains in which the predominating rock type is pre-Cambrian granite.

At the south end of the Sangre de Cristo Range, Magdalena limestone lies on the granite and the younger formations appear in

their respective order and dipping gently to the south. On the west side of the mountains the Tertiary valley fill of the Rio Grande Valley overlaps all pre-Tertiary beds in most places and lies directly on the granite, thus creating a condition similar to that found in the Pecos Valley. The valley fill completely conceals the older formations except in a few places where they have been brought to the surface by faulting, and makes it impossible to detect structures in the sub-Tertiary rocks.

The chances of obtaining oil in the High Cordilleran area or on its immediate borders are so small that the district may be considered as valueless as a prospective oil field.

### THE SOUTHERN CORDILLERAN AREA

The southern Cordilleran area of New Mexico comprises the mountainous region which extends through the center of the State from the main line of the Santa Fe south to the boundary of Texas and Mexico, and southwest to the boundary of Arizona. This region is characterized by the "bolson-fault-block" type of structure which sharply differentiates it from the higher Cordillera to the north. The northern ranges are, commonly, great anticlinal folds more or less modified by faulting. The sedimentary beds are steeply upturned in many places and are more or less altered where deformation has been most intense. In southern New Mexico there are no long ranges, the mountains are monoclinal rather than anticlinal, in only a few places are the beds steeply tilted, and metamorphism is very rarely seen. The southern Cordillera consists of a series of short, relatively low mountain blocks which owe their origin to faulting, arranged in three fairly continuous north-south lines east of the Rio Grande. Except in the disturbed blocks, the formations dip gently to the east or southeast or lie nearly horizontally.

The fault block mountain system of south-central New Mexico was well described by Dutton[2] who likened it to an army of caterpillars which had advanced into the United States from Mexico. After crossing the border, this army broke into two divisions, one of which went northward across central New Mexico, the other northwestward into Arizona and toward the Grand Canyon. Between

[2]Dutton, C. E., Mt. Taylor and Zuni Plateau: U. S. Geological Survey, 6th Annual Report.

these two diverging lines of mountains lies the great Plateau Province of the Southwest.

As possibly productive areas the fault-block ranges are not of any interest, for in most of these blocks granite is exposed at the foot of the fault scarp and the broken and upturned edges of the sedimentary formations outcrop. Oil is found elsewhere in mountanous areas where the rocks are closely folded, as in Ventura county, California, but the monoclinal fault-block structure of the New Mexican ranges has afforded no opportunity for oil accumulation.

West of the mountains is the debris-filled plain of the Rio Grande. Between the individual mountain blocks lies a series of shallow undrained basins known as "bolsons," of which the larger and more important are Tularosa Basin, Estancia Basin, and Jornada del Muerto. These basins, and the valley of the Rio Grande, were once rather deep, but now they are filled to a depth of hundreds of feet by loose, unconsolidated Quaternary gravels and sands washed from the surrounding hills. However, if oil is found anywhere in south-central New Mexico, it is most likely to be found on minor anticlinal folds or along the fault line in the down-thrown and buried fault-blocks which lie concealed beneath the Tertiary valley fill.

Formations ranging in age from pre-Cambrian to Quaternary outcrop in the southern Cordilleran region, but Pennsylvanian and Tertiary rocks are most widely distributed at the surface. Over wide areas the loose Tertiary formations conceal all the older rocks and it may be said safely that the plentitude of Tertiary debris is the geologist's greatest handicap when studying the structure of New Mexico. Pennsylvanian rocks outcrop in all the mountain blocks and around the margins of most of the basins, and the prevailing red color of the Pennsylvanian beds supplies the dominant color note to the whole country.

In the El Paso region rocks representing parts of Cambrian, Ordovician, Silurian, Devonian, Mississippian, and Pennsylvanian time are present. Toward the north the older formations thin out and disappear and at Albuquerque Pennsylvanian rocks lie directly on pre-Cambrian granite. The Bliss quartzite, of Cambrian age, extends no farther north than the San Andreas Mountains; the El Paso and Montoya limestones of the Ordovician have about the same northerly distribution; the Fusselman limestone of the Silurian has not been found as far north as the north end of the San Andreas

Range; and the Devonian Percha shale is even more limited in distribution. The Mississippian Lake Valley limestone has been found as far north as the Ladrones Mountains, but beyond that point no sedimentary rocks older than Pennsylvanian are known.

The outstanding difference in the Paleozoic series in the northern and southern parts of the region is one of lithology. North of Socorro the Paleozoic section contains many thousands of feet of sandstone and shale, and a relatively small thickness of limestone. South of Socorro the thickness of sandstone and shale decreases very rapidly and the limestone content increases even more rapidly as progressively older rocks appear below the Pennsylvanian. North of Socorro the Paleozoic is represented by 1,000 feet of limestone in two formations separated by 1,500 to 1,800 feet of sandstone, shale, and gypsum. South of Socorro the sandstone, shale, and gypsum progressively disappear and at the Texas State line the Paleozoic is represented by 4,900 to 6,900 feet of limestone, 500 to 800 feet of shale, and 300 feet of sandstone.

The sandstone, shale, and gypsum which outcrop north of, and around, Socorro belong to the Manzano group of the Pennsylvanian. The rocks are, for the most part, red in color and give absolutely no evidence of included bituminous materials. A careful study of the whole Manzano group has convinced the writer that it offers little or no chance of being an original source of petroleum.

The limestone which is present in great thickness at the base of the Paleozoic section in southern New Mexico does not contain an appreciable amount of bituminous material except in a few thin beds in isolated localities, yet the future of this region as a producer of petroleum appears to be bound up with the limestone series. Structures favorable for the accumulation of oil exist in the basins, although they will be hard to find, and if the limestone or the shale included in it is an original source of petroleum, the prospects for a large production of oil are good. On the other hand, if the limestone beds have not themselves produced petroleum, and serve merely as storage for oil which has migrated from some outside source, the prospects are discouraging. Most observers consider that marine shale is the original source of most of the world's petroleum, and marine shale is conspicuously absent from the Paleozoic section in south-central New Mexico.

Lithologic conditions in southern New Mexico are in some measure

analogous to lithologic conditions in the oil fields of the Mexican coast. The Tamasopo lime of Mexico is an immensely thick series of limestones, and enormous quantities of oil have been produced from the upper beds of this formation. The rock itself is not more bituminous than are many of the Paleozoic limestones of southern New Mexico, and it is reasonable to suppose that if the Tamasopo limestone produced the oil which is found in it that oil may be found in the Magdalena or underlying limestones in New Mexico. The main question is: Did the oil found in the Tamasopo lime originate in the limestone itself? Over the Tamasopo lime in Mexico lies a thick series of marine shales such as produce oil in many regions of the earth. The solution of the question as to the origin of the oil is dependent on the final answer to the question whether oil ever migrates downward from a superjacent shale to an underlying porous horizon. Opinion is divided on this subject and proof one way or the other is difficult to establish, but it is certain that cases where good evidence of downward migration can be shown are rare. Probably the majority of workers believe that the oil found in the Tamasopo lime originated in the overlying shales, but although this implies downward migration in a stratigraphic sense, it is very doubtful whether it also means downward migration in a gravitative sense. The whole theory of the migration of oil is in a state of change at the present time, and many geologists are coming to believe that petroleum does not migrate for long distances either horizontally or vertically, and that, in most instances, it is found not far from where it originated.

If those observers who believe that oil originates only in shales are correct, there is little hope that southern New Mexico will ever produce an oil field. In this region there is no marine shale lying over the lime, but in its place we find a thick series of "Red Beds" which are anything but bituminous.

On the other hand, if it were definitely known that oil originates in limestones, southern New Mexico would be well worth prospecting. The presence of small quantities of oil in the porous beds at the top of the thick series of limestones in the Pecos Valley has an important bearing on the prospects of the Cordilleran region farther west. If this oil did not originate in the limestone itself, no source for it is evident, and whatever be its origin it is reasonable to expect

oil at least in similar quantity in south-central New Mexico where lithologic conditions are entirely comparable.

A number of wells have been drilled in the basins of southern New Mexico, but most of them appear to have been located on acreage rather than on a favorable structure. Tularosa Basin recently has been a favorite haunt of the wildcatter, but as the valley fill is hundreds of feet thick over much of that basin, most of the wildcats are doomed to failure.

The writer has made a rather careful examination of the Paleozoic section in southern New Mexico, but so little bituminous material was found in the rocks that he is inclined not to be optimistic over the possibilities of finding oil in commercial quantities in this region. In the Plateau Province to the west where many of the same formations are present, the stratigraphy and structure can be studied to much better advantage than in the bolsons of the Cordillerian area, anticlinal folds favorable for oil accumulation are present and can be found without great difficulty, and the Pennsylvanian and perhaps the Mississippian formations can be tested by a well of moderate depth. It would seem to be advisable to devote first attention to the Plateau region, and if some member of the Paleozoic section proves to be productive there, then to direct every effort to finding and testing favorable structures in the Tertiary-filled basins.

### THE PLATEAU PROVINCE

In the writer's opinion, the Plateau Province, west of longitude 106 degrees and north of latitude 34 degrees, is the most promising region in the State of New Mexico in which to prospect for oil and gas.

The Plateau Province in New Mexico is, essentially, an area of Cretaceous rocks. Pennsylvanian formations outcrop in many places and Permian and early Mesozoic formations have a more limited distribution, but Cretaceous rocks predominate. When measured over long distances the sedimentary beds are found to lie flat, or nearly flat. Small faults with a moderate throw are numerous, and locally small well-defined anticlines afford excellent collecting areas for petroleum contained in the deformed beds.

If oil is found in the Plateau region it will probably be discovered in Cretaceous rocks, and chances of finding oil in these formations are bright. Great quantities of oil are being obtained from Cretaceous rocks in Wyoming, and the Wyoming Cretaceous is similar in all

important respects to the Cretaceous of northwestern New Mexico. The Cretaceous areas in the San Juan Basin and the smaller Cretaceous areas northwest and west of Magdalena are probably the most favorable localities in the State.

The oldest rocks found in the district around Magdalena are Mississippian in age, and they are exposed over only a very limited area. The Pennsylvanian formations are similar lithologically to the Pennsylvanian formations east of the Rio Grande and chances of finding oil on structures in the Paleozoic in this district are probably neither greater nor less than chances of finding it on structures in the Tertiary-filled valleys of south-central New Mexico. The surface of the Plateau is not everywhere buried under a mantle of Tertiary debris, however, and chances of locating a favorable structure are much better than in the basins to the east and south. The Manzano group is probably considerably thinner than it is in the Rio Grande Valley, and on many structures a well 3,500 feet in depth would test the lower Pennsylvanian and the Mississippian. Operators who wish to test the Paleozoic horizons in this region should devote careful attention to the areas of Pennsylvanian outcrop around Puertecito and Magdalena.

The Cretaceous rocks exposed in the Magdalena district belong to the older formations of the Cretaceous group, probably no beds younger than Mesaverde being present. The rocks are similar in every way to the corresponding formations in the San Juan Basin and the areas where they outcrop should share attention with the Cretaceous areas to the north.

### THE SAN JUAN BASIN

The San Juan Basin region includes the San Juan Basin proper and a fringe of territory extending on the east nearly to the Rio Grande and on the south to Mt. Taylor Mesa and the Zuni Mountains. The northern boundary lies along the San Juan Mountains in southwestern Colorado and to the west the basin extends into Arizona.

The San Juan Basin proper comprises the area drained by San Juan river. In New Mexico this includes a more or less circular area lying immediately west of the continental divide, and embraces the whole of San Juan county and parts of Rio Arriba and McKinley counties.

South of Gallup is another small basin, bounded by the Zuni

Mountains on the east and drained to the west by Zuni river. This area, known as Zuni Basin, is geologically similar to the larger basin to the north and is commonly associated with it. The combined areas of the two basins is about 140,000 square miles.

The San Juan Basin is a basin both structurally and topographically, and on all sides the formations dip gently inward from the borders toward the center. Around the edge of the basin where the formations outcrop in a series of concentric rings is a series of outward-facing escarpments capped by massive beds of sandstone. Between the sandstone escarpments lie long, gently inclined dip slopes and broad valleys carved in the shales which lie between the sandstones, thus giving to the country the appearance of being built up of a series of steps with "rises" of sandstone and "treads" of shale.

In the center of the San Juan Basin is a broad outcrop of Tertiary rocks, more or less circular in outline, and around the Tertiary in bands of varying width and completeness are the Cretaceous and pre-Cretaceous formations. Not all of the formations outcrop in complete rings around the Tertiary, but the similarity of the formations to a nest of decreasingly smaller saucers piled one inside the other, holds.

The pre-Cretaceous formations in the San Juan Basin do not offer great promise of being productive of oil, and although they range in thickness from 1,300 to nearly 6,000 feet they are of but little interest to the oil producer.

The Cretaceous formations, on the other hand, give promise of yielding petroleum and merit careful study. They are commonly divided into five formations: the Dakota, Mancos, Mesaverde, Lewis and Laramie. The Dakota sandstone commonly consists of a heavy band of sandstone at the bottom, a similar band at the top, with alternating beds of sandstone and shale and some poor coal between. The Mancos is a marine shale of considerable thickness and wide distribution, similar in many ways to the Benton-Pierre shale series east of the Front Range. In many places the Mancos is very black and in general is more carbonaceous than the Pierre, although less carbonaceous than the Benton. Oil is found in many places in the Pierre-Benton series and under structural conditions favorable for accumulation, the Mancos ought to be as promising a primary source of oil as the Benton-Pierre group. In its type locality the Mancos shows no sand. In the neighborhood of Gallup,

the upper part of the Mancos consists of several hundred feet of alternating beds of sandstone and shale with some coal, but the main body of the shale below shows no sandy members that can be traced, although lenses are found here and there.

In its type locality on Mesa Verde, in southwestern Colorado, the Mesaverde formation consists of a heavy sandstone at the base, a similar heavy sandstone at the top, and between these a thick series of alternating beds of sandstone, shale and coal. The formation becomes thicker, more arenaceous, and coarser grained as it is traced southward across the San Juan Basin from its type locality, but it maintains the same general lithologic character. The whole series of upper Mancos and Mesaverde sediments indicates rapidly oscillating conditions of sedimentation in the lagoon or littoral zone of the sea in which the beds were laid down.

The Lewis shale is a greenish or greenish gray sandy shale about 1,000 feet thick in southwestern Colorado, but less than 100 feet thick in the central part of the San Juan Basin. The shale is of marine origin, but does not appear to be highly carbonaceous.

The Laramie consists of a series of soft, friable, brown, tan, or buff sandstones and some shale and coal of both fresh water and brackish water origin. The Tertiary also consists of sandstone and shale. The rocks are coarse-grained, very soft and friable, and have a very characteristic greenish-white, greenish, or gray color with some shade of tan in the sandstones.

If oil is found in the San Juan Basin it will probably be found in the Cretaceous formations because, (1) the pre-Cretaceous formations do not show any of the common evidences of oil, and (2) the pre-Cretaceous formations are too deeply buried over most of the basin. Farther west, in the San Juan River field of northern Arizona, pre-Cretaceous formations are yielding oil and the pre-Cretaceous section of that district merits a closer study than it has yet received.

It has been shown that two types of horizons are necessary before an area can be considered good prospective oil territory: (1) bituminous horizons which supply the petroleum, and (2) porous horizons in which the petroleum may be stored. The Cretaceous area in northeastern New Mexico is rich in shale which might be expected to produce oil, but it is almost destitute of storage horizons. The Pennsylvanian area of south-central New Mexico has a wealth of storage horizons, but bituminous oil-producing horizons are

unknown. The San Juan Basin does not possess quite ideal conditions for the production and storage of petroleum, but conditions are more promising there than in any other part of the State of New Mexico.

Included in the Mancos, Mesaverde, and Lewis formations in the San Juan Basin there is from 800 to 4,000 feet of marine shale, much of it black carbonaceous shale such as is abundantly petroliferous elsewhere in the Rocky Mountain region. The upper part of the Mancos and the Mesaverde together contain from 400 to 800 feet of sandstone sufficiently porous to form admirable storage for migrating petroleum. Anticlinal structures favorable for accumulation of petroleum are by no means rare and we might very well expect that, with both shale and sandstone present in adequate amount, oil will be found in commercial quantity under some of the best of these structures.

The chief infelicity in conditions lies in the distribution of the sandstones which are all concentrated near the middle of the section, and it has been argued that the Cretaceous of the San Juan Basin will not be productive because no continuous and widespread beds of sandstone have been found in either the Mancos or Lewis. A very similar condition exists in Wyoming where the chief production is obtained from the Wall Creek sandstone member of the Benton. The Wall Creek sand lies above a thick bed of Benton shale similar to the Mancos, and is overlain by an even thicker series of Pierre shale which does not differ in any essential respect from the Lewis. The sandstone varies in thickness from less than 100 feet to more than 500 feet, but the best production has been obtained in areas where the Wall Creek is of moderate thickness. The Wall Creek is divided into a number of productive horizons, known in the oil fields as the First Wall Creek, Second Wall Creek, Third Wall Creek, by beds of shale which separate the sandstone beds from one another.

Even a brief examination will show how closely the situation in the San Juan Basin resembles the situation in Wyoming. At the base of the Mesaverde is a bed of sandstone nearly 200 feet thick and sufficiently porous in most places to form a good storage horizon. A similar sandstone lies at the top of the Mesaverde immediately underneath the Lewis, and separated from the lower sandstone by a considerable thickness of shale. Even if no oil has migrated downward from the Lewis into the underlying sand, the shale serves as an

adequate and impervious seal for the possible oil horizons below.

Just enough oil has been found already in the Mesaverde along the south side of the San Juan Basin to encourage further drilling. The Mancos shale may never have produced large quantities of oil, and the overlying sandstones may be barren, but until this has been conclusively proved by several tests drilled on good structures, the writer is inclined to regard the San Juan Basin as the best prospective oil territory in the State of New Mexico.

## SUMMARY

The greater part of the State of New Mexico does not look highly favorable as a future source of petroleum in commercial quantities.

Northeastern New Mexico possesses great thicknesses of marine shales in Red River Valley, but good storage horizons are not present in the shale series and it is very difficult, if not impossible, to locate structures favorable for accumulation of oil.

The Santa Rosa-Tucumcari region is practically barren of carbonaceous marine shale, and recent discoveries lead to the belief that it may be barren of marine limestone also. Structures are plentiful and are easily found, but their origin is in question and many of them are probably unfavorable.

The Roswell-Dayton district in Pecos Valley has produced a little oil and may produce more if the position of favorable structures can be located closely, and tests drilled on them. Large production is probably not to be looked for.

The oil possibilities of south-central New Mexico are bound up with the possible productivity of the thick series of Paleozoic limestones. If these prove to be original sources of petroleum, the area may yield good production if it be possible to overcome the handicap imposed on prospecting for structures by the mantle of Tertiary debris.

The Plateau Province of New Mexico offers the best chance for future production. Both marine shales and porous sandstones are present under adequate capping of shale, and structures are neither rare nor hard to find. The Cretaceous areas of western New Mexico merit the attention of the oil seeker.